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PB-298 227

A History of Land Application as a Treatment Alternative

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Apr 79

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PROJECT OFFICER'S NOTE: Both of the authors have been directly involved in the land application of wastewaters on an international basis. Dr. Jewell's interest in the history of applying municipal wastewaters to the land evolved from contacts during postdoctoral study at the Water Research Center in Stevenage, England, and has intensified through continuing research involvement at the University of Texas, the University of Vermont, and now Cornell University. Mr. Seabrook, now retired, was personally involved in design of a land application system for an industrial source in the 1940's. His continued interest in land application techniques in general, and more specifically, the history of land application has been stimulated by visits to operating systems around the world. Long term continuous operations such as the Werribee Farm serving the City of Melbourne, Australia, since 1897 have been of particular interest to the authors and inspired them to address the history of land application of wastewaters.

NOTES

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TECHNICAL REPORT DATA

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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO. PB298227
4. TITLE AND SUBTITLE A History of Land Application as a Treatment Alternative MCO-40		5. REPORT DATE April 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO. MCD-40
9. PERFORMING ORGANIZATION NAME AND ADDRESS Same as Box 12		10. PROGRAM ELEMENT NO. 2BG647
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Office of Water Program Operations U.S. Environmental Protection Agency Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Technical Report
		14. SPONSORING AGENCY CODE EPA 700/02

15. SUPPLEMENTARY NOTES

→ The report describes

16. ABSTRACT

→ Why has land treatment been adopted in so few instances? This review was conducted to attempt to determine whether the history of land treatment could assist in explaining the reasons behind the apparent reluctance to use this wastewater treatment option, and to provide a basis of judging its future prospects. The approach to explain the major shifts that have occurred throughout the history of land treatment was to interweave the influences of social-public health concerns, legal issues, and technological developments.

In ancient Greek and Roman times, public sanitation, the efficient removal of wastes by running water, and even land application of wastewaters were practiced. Shortly after this time and up until the early 1800's, public sanitation was almost non-existent.

Most of the early developments in land treatment occurred in Britian during the period from 1840-1890. The earliest system that is well documented is the sewage farm for Edinburgh, Scotland begun in 1650.

(See continuation on next page.)

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Pollution Control	Land Treatment Land Application	

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 97
	20. SECURITY CLASS (This page) Unclassified	22. PRICE PC A05 MF A01

EPA Form 2220-1 (9-73)

ctd fr BRS

Wastewater treatment alternatives in use in Europe were being examined by the authorities in the U.S. in the 1890's. The image which they saw was characterized by increasing debates over the alternatives, numerous overloaded and poorly managed systems, and a rapidly developing water supply treatment technology. During the period from 1890 to 1905, land treatment was considered to be the most effective alternative in the U.S. and was used in most communities with sewage treatment. But from the beginning, American engineers considered sewage farming, intermittent filtration and other methods of land application of wastes to be "disposal" systems. The last major text to present significant material on land application of wastes occurred in 1930, and this information indicated that land "disposal" of wastewaters was only a viable alternative in the southwestern part of the country. From 1930 to the early 1970's, no major engineering text included a section on land treatment.

Today, over 3000 land treatment systems are in use in the U.S. and some have been effective for more than half a century. Surveys of land treatment system failures have shown that most convert from land treatment to discharge technology because of population expansion around the site, and not because of a failure of the renovation capability of the soil.

EPA 430/9-79-012

TECHNICAL REPORT

A HISTORY OF LAND APPLICATION AS A TREATMENT ALTERNATIVE

by

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April 1979

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MCD-40

"Even the most ignorant peasant is quite aware that the rain falling upon his dung-heap washes away a great many silver dollars, and that it would be much more profitable to him to have on his fields what now poisons the air of his house and the streets of the village; but he looks on unconcerned and leaves matters to take their course, because they have always gone on in the same way."

From: The Natural Laws of Husbandry.
p. 275
1863
Justus von Liebig

SUMMARY

There are more than 3000 land treatment systems in the U.S. receiving municipal and industrial wastewaters not including the 15 million plus septic tanks that treat 3 billion gallons per day of wastewater. Thus, it is logical to consider land application as a wastewater treatment option in all cases involving public funding as mandated by P.L.92-500, a law intended to restore and maintain the integrity of the Nation's waters. However, relatively few practicing engineers are familiar with land treatment technology, and since this law was passed less than 10 percent of all new systems have utilized this option. Why has land treatment been adopted in so few instances? This review was conducted to attempt to determine whether the history of land treatment could assist in explaining the reasons behind the apparent reluctance to use this wastewater treatment option, and to provide a basis of judging its future prospects. The approach to explain the major shifts that have occurred throughout the history of land treatment was to interweave the influences of social-public health concerns, legal issues, and technological developments.

In ancient Greek and Roman times, public sanitation, the efficient removal of wastes by running water, and even land application of wastewaters were practiced. Shortly after this time and up until the early 1800's, public sanitation was almost non-existent. Explicit descriptions of unsanitary conditions in densely populated areas of Europe were common. Large piles of human excrement were allowed to accumulate between closely spaced houses; and, when convenient, these wastes were either carried to fields to be used as fertilizers or they were washed into the rivers and streams.

Most of the early developments in land treatment occurred in Britain during the period from 1840-1890. The earliest system that is well documented is the sewage farm for Edinburgh, Scotland begun in 1650. It was not until 1850 that installation of sewers, Chadwick's system of "arterial drainage,"

caused some method of treatment to be essential to alleviate gross pollution of surface waters. Although the germ theory was not well accepted and understood until 1890, the disastrous epidemics that raised the annual death toll of affected areas to nearly 10 percent of the total population were associated with human wastes. These water borne epidemics resulted in great social and legislative pressure to control sewage. Since the nutrients in waste had been shown to have a beneficial impact on crop growth, sewage farming was sought as the only adequate technology, and promoted as being profitable up until the 1890's. The literature of this time clearly reflects the fact that although the data from sewage farming was largely empirical, pollutant and soil interactions were considered to be a purifying treatment process, that it was a living system that possessed certain limitations that could be overloaded by applying too much waste, and that when overloaded it would result in system failure.

Several key technological developments were responsible for changing the status of land treatment from being the only adequate treatment system to one of many alternatives between 1840 and 1890. Almost all the wastewater treatment processes were developed and tested between 1850 and 1890 - chemical precipitation, activated carbon adsorption, trickling filters, biological contact beds, and intermittent filtration. Knowledge of the disease carrying agents provided insight necessary to judge the public health hazards of effluents, and in the 1890's it became clear that sand filtration of sewage could remove nearly all the bacteria. Water supply treatment by filtration was widely adopted after this discovery; chlorine was introduced in 1910 and major epidemics of typhoid and cholera were eliminated. Thus, by the late 1890's discharge of partially treated wastewater effluents was considered to be safe and the most cost effective alternative. Previously promoted as being profit making ventures, land treatment of raw sewage had been shown by this time to be unprofitable. Many systems installed in the mid 1800's were used for 30 to 50 years without increasing their size in response to growing populations. Overloaded conditions resulted which provided highly visible negative testimonials to their effectiveness.

Wastewater treatment alternatives in use in Europe were being examined by the authorities in the U.S. in the 1890's. The image which they saw was characterized by increasing debates over the alternatives, numerous overloaded and poorly managed systems, and a rapidly developing water supply treatment technology. During the period from 1890 to 1905, land treatment was considered to be the most effective alternative in the U.S. and was used in most communities with sewage treatment. But from the beginning, American engineers considered sewage farming, intermittent filtration and other methods of land application of wastes to be "disposal" systems. The last major text to present significant material on land application of wastes occurred in 1930, and this information indicated that land "disposal" of wastewaters was only a viable alternative in the southwestern part of the country. From 1930 to the early 1970's, no major engineering text included a section on land treatment.

By 1950, there were signs that the usual approach to pollution control was no longer acceptable. The first major wastewater treatment legislation was passed in 1956 (Water Pollution Control Act, P.L.84-660). The eutrophication issue which arose in the mid 1950's served to emphasize to the American public that discharge of partially treated wastewaters into waterways was causing serious deterioration of surface water quality. A major effort to classify all surface waters in order to define the quantity of pollution which could be assimilated by receiving streams was the major focus of pollution control technologists up until the early 1970's. As the focus of pollution control shifted to plant nutrients, the rational approach of dilution as a solution to pollution and discharge of secondary sewage became much less desirable. In numerous studies in the U.S. and elsewhere, it was shown that the soil had a large assimilation capacity for many pollutants and that wastewater and sludge could be beneficially recycled in land treatment systems. Thus, when PL92-500 was developed, the alternative of land treatment to eliminate discharges of partially treated wastewater was a highly attractive alternative.

Today, over 3000 land treatment systems are in use in the U.S. and some have been effective for more than half a century. Surveys of land treatment system failures have shown that most convert from land treatment to discharge technology because of population expansion around the site, and not because of a failure of the renovation capability of the soil. Economic studies indicate that land treatment can be a highly cost effective technology. But several barriers exist to widespread implementation of land treatment technologies. First, in all wastewater treatment situations involving public funding, the technical community must include a comprehensive evaluation of land treatment according to the new policy announced by EPA in 1977 without the background to enable it to do so. Land treatment is now considered as the technology of choice, and unnecessarily strict state regulations which make it uneconomical will cause federal financial support to be withheld from projects calling for discharge technologies. Second, the philosophy of land treatment or soil treatment systems must replace the "disposal" concept. Third, the large body of empirical information needs to be replaced by fundamental definitions of the pollution control cycles in soils, particularly those relating to water, organics, toxic elements, and nitrogen. Finally, the topic of the use of land for waste treatment needs to be emphasized in education of environmental engineers, agricultural engineers, agronomists and others who must cooperate in designing these systems. This final barrier will be partially eliminated by the availability of a new EPA design manual for land treatment of municipal wastewaters and a short-course educational program developed by Cornell University.

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ACKNOWLEDGEMENT

When P.L.92-500 was passed in 1972, the senior author of this report was one of the many environmental engineers who questioned the competitiveness of land treatment over the conventional unit process treatment and discharge technology. This attitude was rapidly replaced by a new respect for this wastewater treatment alternative as more information was uncovered that showed the proven cost-effectiveness of land treatment of sewage and sludges. This historical review has provided additional insight into the evaluation of land application of wastes. Consideration of a number of factors which have influenced development of wastewater treatment clearly indicate why the technology evolved, why it was nearly totally abandoned in the early 1900's and why it has been brought back to a dominant position as a tool for water pollution control. Based upon the understanding obtained in this review, the authors feel that the future of effective wastewater control will involve widespread adoption of various combinations of land treatment systems.

No attempt was made here to provide a comprehensive review of all the events that affected water pollution control with land treatment, since this would have been beyond the scope of the study. An effort was made to correlate a wide range of events in Europe and the U.S. during the period from 1800 to the present which would provide a better technical perspective of one alternative for wastewater treatment. Many of the authors' friends and colleagues provided valuable assistance in developing the broad overview. Of particular assistance was the input and detailed review given by R.E. Thomas. Although the time frame of this study was restricted, rapid responses and valuable insights were also received from Messers D.A. Ardern, Thames Water Authority, Lee Division, England; A.M. Bruce, Head, Sludge Technology Section of the Water Research Center at Stevenage, England; A.E. Collins, Divisional Manager Thames Water, Chiltern Division, England; and C. Teitjen of the Institute für Pflanzenbau Und Saatgutforschung, West Germany.

Thanks go to S. Giamichael for assembling and typing the manuscript.

INTRODUCTION

Concern for water pollution control has grown considerably since passage of the Federal Water Pollution Control Act of 1956 (P.L.84-660). Although this Act was amended several times, the most significant change occurred in 1972 with the passage of P.L.92-500 which reflected the desire of the people to control water pollution as soon as possible and as efficiently as could be afforded. Land application of wastes was one of the technologies proposed as an alternative to be considered in all cases because of the high efficiencies of this pollution control option achievable at low cost. Only strong lobbying efforts prevented the option of land treatment from being promoted as the standard against which other wastewater treatment alternatives should be judged.

The goal of restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters involved a commitment of $18 billion -- a higher funding level than either the interstate highway system or the space program. To achieve "zero discharge" of wastes either reuse of wastewater or highly efficient land treatment systems would be required. However, for a number of reasons the pollution control technical community was not ready to adopt land application of wastes as a major alternative in the fight against water pollution. In fact, the suggestion that this alternative could provide the solution to water pollution was met with doubt from many engineers who were well trained in the areas of unit process treatment and discharge (Rogers, 1972; Egeland, 1973).

During the four years following the passage of P.L.92-500 more than 2000 new wastewater facilities were built, but only about 10 percent of these included land treatment (Freshman, 1976; Thomas, 1977). In order to emphasize the fact that it had become mandatory to consider the option of land treatment as of July 1, 1974, the U.S. Environmental Protection Agency (EPA) Deputy

Administrator issued a memo on November 1, 1974 which directed each EPA regional administrator to assure that the option of land treatment was carefully considered before approving EPA support of any wastewater treatment facility. Because of the continuing reluctance of the pollution control community to include comprehensive evaluation of land treatment technology in its decision making processes, a memo was issued by the EPA administrator on October 3, 1977 in order to clarify and define EPA's policies in this area (Costle, 1977 - see Appendix A). This memo clearly indicated that land treatment technology must form the basis for comparison of all other alternatives. This reinforcement of the intent of P.L.92-500 emphasizes the need to understand the historical aspects of recycling wastes to the land.

Lack of experience and knowledge of the design and operation of land treatment systems was reflected in passage of highly restrictive state legislation shortly after the passage of P.L.92-500. Effectively, many states assisted in avoiding the adoption of land treatment of wastewater by passing legislation which made it difficult for this option to be considered the most cost effective treatment alternative (Morris and Jewell, 1977). In most cases, state regulations require or strongly urge secondary pretreatment prior to land application of wastewaters. Since secondary treated effluent is quantified as a dischargeable quality by EPA, it is obvious that this type of specification makes the land treatment alternative uneconomical and thus not eligible for federal grant support at the 75 percent level provided for the most cost-effective alternative. The recent EPA memo (Costle, 1977) addresses the issue by noting that "whenever states insist upon placing unnecessarily stringent preapplication treatment requirements upon land treatment, such as requiring EPA secondary effluent quality in all cases prior to application to land, the unnecessary wastewater treatment facilities will not be funded by EPA."

HISTORICAL REVIEW APPROACH

The obvious question arises - "Why is land application of waste not being selected more often?" This historical review was written to assist in answering this question.

Objectives

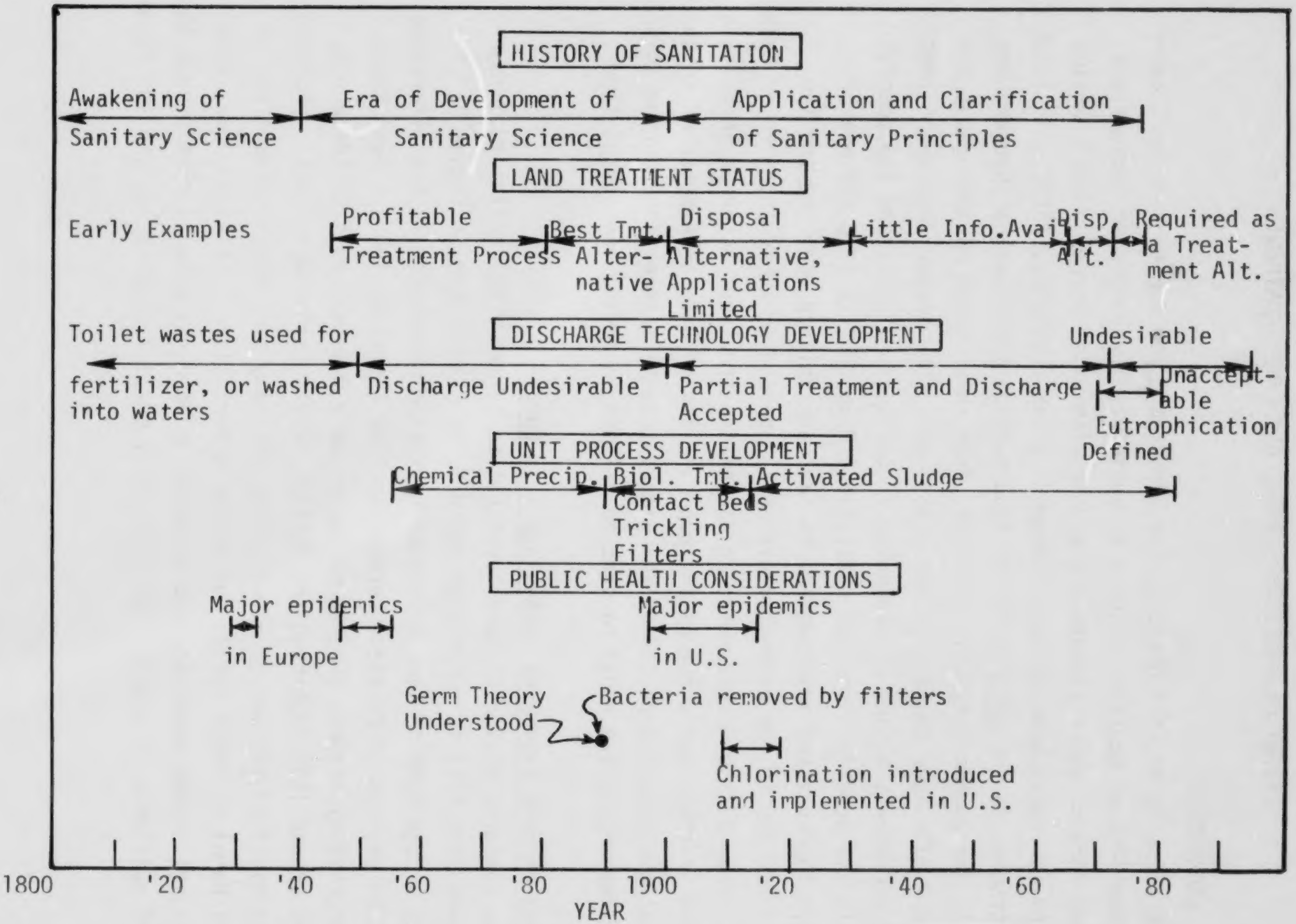
Land application was the only recognized technology before the development of unit process wastewater treatment technologies. The present reluctance to include this as a treatment option differs greatly from activities in recent history of water pollution control. It was intended that this paper would clarify the following: why land application of wastes evolved into the main treatment alternative in the 1800's, why it was subsequently relegated to a disposal alternative, why it is now being rejuvenated as the most effective pollution control alternative, and what are its prospects for use in the future. Land application of sewage sludge and septic tanks will not be included in this review.

Scope of Study

In order to clarify the reasons for major shifts in technology it is necessary to correlate the impact of a wide range of factors. This is particularly true of the issues which must be taken into account in unraveling the reasons why land treatment was nearly completely dismissed after many years of being highly effective. Some of the factors which were included in this review are:

- treatment efficiency - difference between disposal and purification philosophy,
- influence of major technological developments,
- public health - relationship of treatment technology to disease in populated areas,
- aesthetics and the importance of appearance,
- definition of pollution, relationship of this definition to process efficiency,
- natural pollutant assimilation capacities, stream pollution and dilution as a solution to pollution, and
- economics of the treatment situations.

Although the relationships of public health, process efficiency, treatment efficiencies, and the other factors listed above to land treatment may seem overly complex, the authors feel that it is a complex combination of these factors which must be used to explain the reasons behind the changing status of land treatment. Figure 1 summarizes some of these events and the time at which they occurred. This general figure will be used as a basis for discussion in the following sections.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DISCHARGE TECHNOLOGY DEVELOPMENT
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Discharge Undesirable
Partial Treatment and Discharge Accepted
Undesirable
Unacceptable
Eutrophication Defined
UNIT PROCESS DEVELOPMENT
Chemical Precip.
Biol. Tmt. Contact Beds Trickling Filters
Activated Sludge
PUBLIC HEALTH CONSIDERATIONS
Major epidemics in Europe
Major epidemics in U.S.
Germ Theory Understood
Bacteria removed by filters
Chlorination introduced and implemented in U.S.
1800
'20
'40
'60
'80
1900
'20
'40
'60
'80
YEAR

Figure 1. Chronological development of factors partly responsible for the changing status of land treatment of wastewaters.

HISTORY OF SANITARY SCIENCE AND LAND TREATMENT

GENERAL BACKGROUND

According to ancient history, the Greeks and the Romans were well aware of the benefits of basic sanitation to society. There are also indications that some form of water closets and sewers with water borne domestic wastes were used for conveyance to land treatment areas (Doxiadis, 1973). At least two references in the Bible refer to land application of wastes (Deuteronomy xxiii, 13 and Judges iii, 20). However, from this period on throughout the Dark and Middle Ages sanitation was a lost art. The period from about 1800 to 1850 represents a time of awakening of the professionals and the general public to the need for improved sanitation. From 1850 to 1910 the era of great developments and advancements in sanitary science occurred and the period from 1910 to the present represents a period of implementation of technology. Many of the developments in wastewater treatment occurred in Britain from 1850 to 1910, and whenever any municipality of size in America or on the Continent would be interested in the latest treatment technology during this time, a representative would be sent to Britain to review the status there.

Evolution of Land Treatment Technology - In Europe

The changing status of land treatment in terms of the estimated number of systems installed in Britain and the U.S. is illustrated in Figure 2. The earliest sewage farm or sewage irrigation system documented in the literature appears to be that of Bunzlau, Germany in 1531 (Gerhard, 1909). Next comes the Crargentinny Meadows project which became a practice outside Edinburgh, Scotland around 1650 (Robinson and Melliss, 1877; Stanbridge, 1976). Farmers at first diverted the sewage flowing from the city in a small stream (called the Foul Burn) to their fields for use as a fertilizer. It is no doubt that this project became known and was accepted as an early example that proved the value of nutrients in sewage. Another early project that influenced the farmers

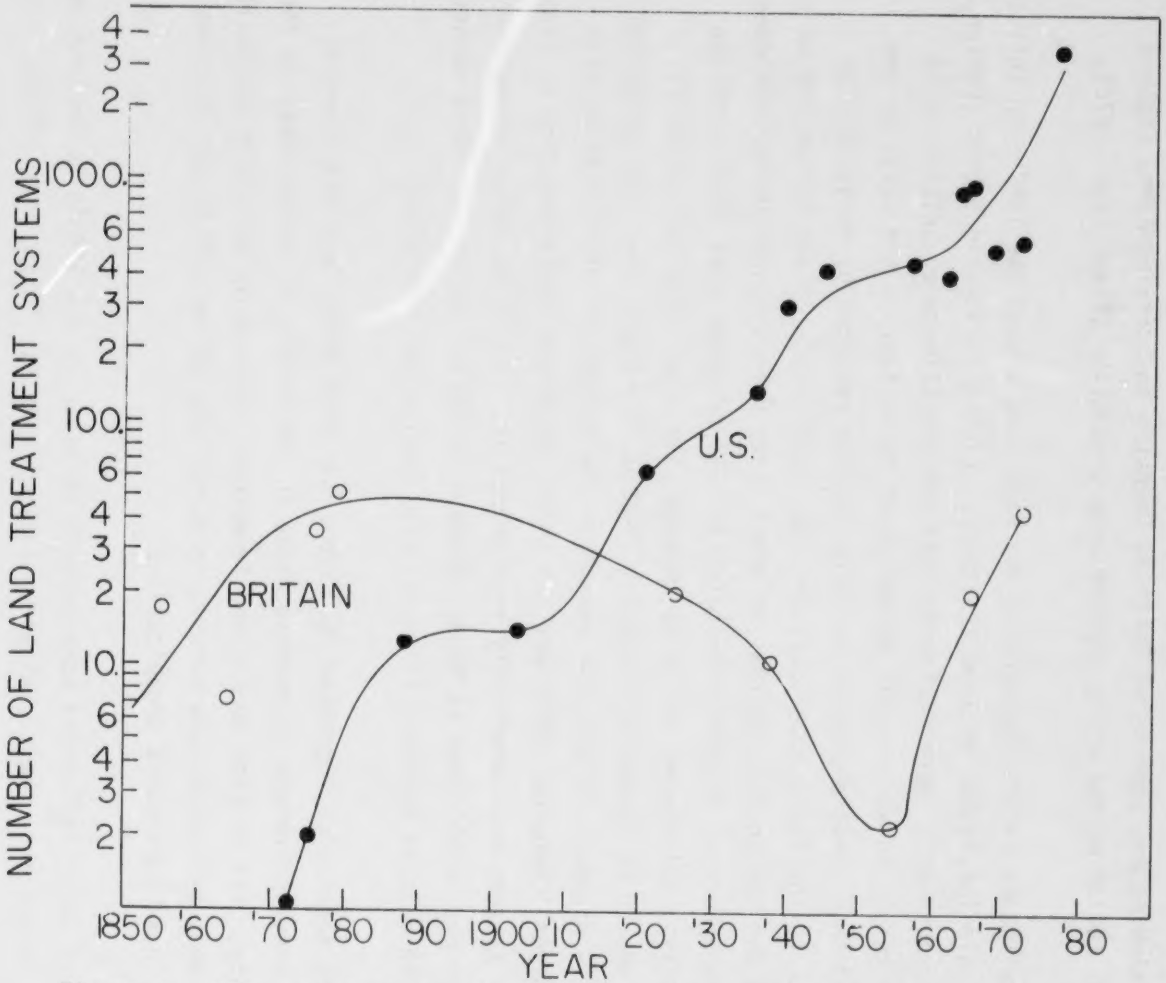

Figure 2. Chronological development of number of places using land treatment. Data summarized from Austin, 1857; Krepp, 1867; Rafter and Baker, 1894; Rafter, 1897; Rafter, 1899; Fuller and McCintock, 1926; Hutchins, 1939; Hill, et al., 1964; Jenkins, 1970; Thomas, 1973; and Thomas, 1977. Note that the number of grass filtration facilities in Britain and the number of septic tanks are not included with this data.

in their thinking was when James Smith at Deanston in Stirlingshire, England showed that toilet wastes could improve crop production (Stanbridge, 1976).

Several major events occurred at the same time around the 1840's to influence the full scale initiation of land treatment. Liebig (1840) and others (Denton, 1842) had convinced a large following that the wet climate of Britain would eventually result in washing all of the plant fertilizer in the soils to the oceans; and that these nutrients could be largely replaced by recycling the sewage back to the land. Secondly, general requirements of sanitation had been recognized and continuous supplies of water under pressure were being developed for many households. Sir Edwin Chadwick in 1841 proposed that along with the water supplies, all houses should be sewered, i.e., an "arterial system of drainage" should be installed (Chadwick, 1965). Sir Edwin Chadwick recognized that Vetch's proposal to pump the sewage to the fields and distribute it with a hose and jet (Chadwick, 1965) was the answer to proper implementation of sewage collection systems and immediately recommended it. The first spray irrigation sewage farm was established at Rugby, England in 1853. One of the first sewage farms in the U.S. at Pullman, Illinois, also used spray irrigation.

As the population increased in Europe sanitary conditions deteriorated. There are many references to excreta piles in the middle of narrow lanes in the high density, back to back houses and tenements. This material would eventually be carted away by contractors working to directions of the old Parish Vestries - the first local government organizations.

Several major influences were growing stronger in the 1840's in England to force the issues into the social and political arenas. First, many of the waterways were being heavily polluted with runoff and direct discharge of domestic and industrial wastes. The aesthetics and the public health aspects of these waterways were of concern. Although the germ theory had not been developed, it was felt that sewage contaminated waters were in some way responsible for diseases. It was most commonly thought that volatile products coming from the waters caused disease. Disasterous epidemics were occurring in large cities and caused major social unrest.[1] The Cholera epidemic of 1832-33 in London was followed by another in 1848, one in 1849 which claimed 14,600 lives, and one in 1854 which claimed 10,600 lives (Gerhard, 1909). Throughout the period from 1840 to 1910, it appears that the epidemics and the fears of diseases were responsible for developing public support needed to implement sewerage systems, sewage treatment and water treatment systems.

Several events that had a major impact on agriculture which were also developing in the 1840's eventually had a negative impact on land treatment. The importation of fertilizers was initiated in Britain in 1841. By 1862, 122,000 tons per year of Peruvian guano was being imported (Stanbridge, 1976). In 1842, a patent was issued to manufacture superphosphate fertilizer from phosphate rock using an acid process (Lawes, 1842). In the early 1860's, concentrated feeds were being given to stabled animals. This practice led to a readily available supply of plant nutrients. Thus, at about the time that the fertilizer value of domestic wastewaters and sludges was recognized, other competing sources for plant nutrients were becoming available.

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[1] The deplorable condition of London's basement population in 1847 was described in the following quotes:

> *"There are hundreds, I may say thousands, of houses in this metropolis which have no drainage whatever, and the greater part of them have stinking, overflowing cesspools. And there are also hundreds of streets, courts and alleys that have no sewers; and how the drainage and filth are cleaned away and how the miserable inhabitants live in such places, it is hard to tell.*
>
> *In pursuance of my duties from time to time, I have visited very many places where filth was lying scattered about the rooms, vaults, cellars, areas, and yards, so thick and so deep that it was hardly possible to move for it. I have also seen in such places human beings living and sleeping in sunk rooms with filth from overflowing cesspools exuding through and running down the walls and over the floors . . . The effects of the effluvia, stench, and poisonous gases constantly evolving from these foul accumulations were apparent in the haggard, wan, and swarth countenances and enfeebled limbs of the poor creatures whom I found residing over and amongst these dens of pollution and wretchedness."*
>
> *John Phillips in a report on*
> *conditions of London basements*

The Rugby, England sewage farm established in 1853 was one of the first to use the spray irrigation system as proposed by Vetch and recommended by Chadwick. Many systems were installed shortly after this period in Britain and in other countries. By 1876, 35 towns used land treatment in Britain, 60 had direct discharge to rivers, 21 had direct discharge to the sea, and 19 towns used cesspools (Rideal, 1906). The profitable status of sewage farming in England was summarized by Birch in 1879 for 50 different instances of sewage farming (see Appendix B for summary of systems). Of the 100 or more land owners using sewage, about 83 percent paid the municipality for its use at this time.

Birch (1879) mentions that there was a great deal of discussion surrounding the question of chemical precipitation versus the use of sewage farms. This would appear to be the beginning of discussions about which type of treatment was appropriate to provide environmental protection at a reasonable cost.

By 1870 it became increasingly apparent that the demands of sewage purification and agriculture were not always compatible. The crops did not need to be irrigated at various periods, and if the sewage must be applied it could adversely affect the crop. It was reported that a considerable amount of "by passing" to rivers began to occur at the English sewage farms especially during harvest and in the cold weather (Fuller and McClintock, 1926).

The first successful attempt to convert soil treatment into a controlled unit process operation was when Sir Edwin Franklin developed the intermittent filter (Second Commission on River Pollution, 1870; Dunbar and Calvert, 1908). This was first reported by the Royal Commission on Metropolitan Sewage Discharge in 1870. The following comments are from the report regarding this process:

> *"...(Franklin) instituted a series of experiments, and established the fact that by passing sewage through a suitably porous soil not constantly but intermittently, a high degree of purification could be ensured, the object of the intermittence being to aerate the filter and so give an opportunity for the purifying action of the oxygen. It is explained that a filter so used is not a mere mechanical contrivance, but a chemical apparatus for oxidizing and thus altogether transforming, as well as for separating, the filth of dirty water.*

> *These experiments on the filtration of sewage through various materials leave no doubt that this liquid can be effectively purified by such processes, and that probably any variety of porous and finely divided soil may, be employed for this purpose.*
>
> *With a properly constituted soil well and deeply drained, nothing more would be necessary than to level the surface and to divide it into four equal plots, each of which in succession would then receive the sewage for six hours. In this way the sewage of a water-closet town of 10,000 inhabitants could, at a very moderate estimate, be cleansed upon five acres of land, if the latter were well drained to the depth of six feet."*

In futher explaining the process, Franklin makes the following analogy:

> *"A field of porous soil irrigated intermittently virtually performs an act of respiration, copying on an enormous scale the lung action of a breathing animal; for it is alternately receiving and expiring air, and thus dealing as an oxidizing agent with the filthy fluid which is trickling through it. And a whole acre of soil, 3 or 4 feet deep, presenting within it such an enormous lung surface, must be far superior as an oxidizer, for dealing with the drainage of 100 people, to any filter that could be practically worked for this purpose."*

There are several points that should be noted in the above quote. First, sewage farming and this new process were considered to be sewage purifying or treatment processes. The term "disposal" in relation to land application is a modern term and was rarely applied in relation to the above processes. Denton (1870) clearly indicated that:

> *"Most authorities know that it (sewage) must pass through a considerable quantity of soil before it is suited for discharge to rivers. By thus increasing (through drainage), horizontally as well as vertically, the amount of soil through which the sewage will travel, it will become oxygenized in the same way as is the case with sewage passing several miles down a river."*

Thus, 20 years before the significance of biological processes and before the existence of bacteria were known, the capability of soils as a treatment system was known. Further, the concept of rate limiting or loading rate in relation to an assimilation capacity was well understood, and oxygen or aerobic conditions were stated in a number of places to be absolutely necessary for the continued operation of soil treatment systems. In 1871 an engineer prominent in land application of wastes wrote a book entitled, "Sewage, the Fertilizer of Land and Land the Purifier of Sewage" (Denton, 1871).

Because intermittent filtration was such a new process and a unique approach, the England Rivers Pollution Commissioners suggested a number of objections that would be raised (1868):

> *"First, that the plan is wasteful, is not fitted for producing crops. Secondly, that the concentration of so large an amount of sewage on a small area will produce greater nuisance than other modes of treatment. Thirdly, that the soil receiving such large quantities of sewage will, after a time, become overloaded and clogged, so losing its filtering power. Fourthly, that the cost of preparing the land is so great as to preclude its adoption; and fifthly, that the success of the process would be doubtful with ordinary management on a large scale."*

An extensive publication by Denton citing 14 years of operational experiences with intermittent filtration with a number of systems provides considerable insight into the answers given to the above objections (Denton 1885). In general, all were shown through full scale operations to have little basis in fact. It is interesting to compare the above objections to those brought up by critics of land treatment today.

In 1871, Denton successfully applied the intermittent filtration concept at Merthyr Tydfil, Glamorganshire, Great Britain. Following this application, 12 additional installations were made (Denton, 1877).

In 1877, Denton suggested that treatment and disposal of sewage must be accomplished by "the best practicable and reasonably available means." It was also in 1877 that Denton suggested that the best treatment system consisted of a combination of intermittent filtration and sewage farming. This suggestion was made in order to make land treatment more flexible during bad weather, crop harvest and other periods when it was difficult to use the sewage to advantage in agriculture.

In 1869 this technology reached its peak in England and Denton predicted that "all towns will eventually use land treatment of ... wastewaters" (Denton, 1877).

Large sewage farms were begun during this period at Paris, France (in 1869--Manning, 1876) and at Berlin, Germany, (in 1874). The Berlin system was to become one of the largest in the world, and it also represented the only example where unit processes such as trickling filters were abandoned in favor of expansion of the sewage farm as the population expanded. This occurred in 1930 when unit processes were being adopted in most of the remainder of the world.

The status of land treatment in 1877 is reflected by conclusions drawn by Denton from a series of lectures on Sanitary Engineering:

> "I. *That the liquid refuse of towns, villages, hamlets, institutions, and dwellings, can only be continuously, effectively, and economically cleansed and rendered legally admissible into inland rivers by application to land.*
>
> II. *That when agricultural land can be obtained for the purpose at a cost not exceeding fifty percent above its ordinary saleable value, resulting in a rent-charge not exceeding 50 shillings an acre, the sewage should be applied to it on the principle of surface irrigation on a wide scale, combined with intermittent filtration through a small proportion of the land area purchased.*
>
> III. *Sewage farming can never be remunerative...so long as (the farmer) is compelled to take and cleanse the sewage at all times and under all conditions. It is, therefore, essential that a properly prepared plot of land for intermittent filtration should be held by the local authority, to receive the sewage when not wanted by the farmer."*

The Committee on the Sewage of Towns appointed by the Local Board gave the following conclusion in 1862 regarding the status of land treatment of sewage:

> "9. *The earth possesses the power of absorbing from sewage all the manure which it contains, if the dressings in volume are proportioned to the depth and quality of the soil."*
>
> "15. *Sewage may be advantageously applied to land throughout the entire year."*
>
> "18. *Large dressings and an over-taxed soil may pollute surface streams, subsoils, and shallow wells."*

A list of early land treatment systems, the dates which they were placed in service, and their termination date, is given in Appendix C.

From the 1880's to the late 1890's there were increasing discussions as to whether direct discharge, unit process treatment and discharge, or land treatment was the best alternative. Sedimentation, chemical precipitation, screening, and other pretreatment was often combined with some form of land treatment. By the turn of the century, the towns had expanded resulting in increasing loadings on sewage farms with populations moving closer. Because of the inability of these systems to expand, they were largely replaced with percolating (trickling)filters and later, activated sludge. Most sewage farms have been closed today in Britain.

Land treatment is still used extensively in Britain for final "polishing" of the effluent from modern wastewater treatment facilities. Grass plots are used as overland flow systems to achieve additional suspended solids and nutrient removal (Institute of Water Pollution Control, England, 1974). Four to six plots of grass are arranged with a slope of about 1 in 100 with channels at the top to apply and at the bottom to collect the runoff. The loading rate of effluents on these plots is about 1.2 m^3 per m^2 per day (Ardern, 1977). They are periodically dried and the grass is removed. Typical results from one large facility (35,000 people) is to reduce the BOD_5, SS, and ammonia to below 10 mg/ℓ, each resulting in a 50 percent, 55 percent, and 73 percent reduction in these parameters, respectively (Ardern, 1977).

Evolution of Land Treatment Technology - United States

The first comprehensive reviews of sewage disposal in the U.S. noted that the discussion of the various approaches to waste-water treatment was increasing (Rafter and Baker, 1894; Rafter, 1897, 1899). Rafter's work provides insight into wastewater treatment in the early days of development of land treatment in the U.S. An annotated bibliography prepared by Rafter (1899) is included as Appendix F. Even though land treatment had begun to be replaced by discharge technologies in Europe in the late 1800's, Rafter felt that land application of wastes was much more effective than any treatment and discharge alternatives. A summary of the general principles discussed by Rafter (1897 - 1899) indicated that the technology was highly sophisticated by this time and that the main principles were surprisingly well defined (see Appendix E). For example, it was suggested that high rate intermittent filtration areas be included in crop irrigation systems so that a treatment area would always be available when wastewater could not be profitably applied to crop land. Issues such as public health were not considered to present significant problems.

Rafter's second report (1899) focused on the status of treatment in the U.S. Most of the 143 sewage treatment facilities in the U.S. and Canada as of 1899 were land treatment systems. The controversy over chemical precipitation taking place in Europe did little to convince Rafter of the advantages since he noted that: "All town authorities need to understand that, with other conditions equal, the capitalized cost of land purification processes is ordinarily less than that of the chemical. Farmers in the vicinities of towns need also to understand this, as well as the benefits to themselves to be derived from the utilization of sewage in agriculture."

The first sewage crop irrigation system in the U.S. was constructed in 1872 in Augusta, Maine, with a flow of 7000 gpd. A detailed list of facilities included in Appendix C includes those cited by Rafter (1899). By the late 1880's, several eastern cities and 8 western cities used some version of sewage farm and 6 intermittent filters were in use (Rafter and Baker, 1894).

The model community in Pullman, Illinois, built by the Pullman railroad manufacturing company, utilized the spray irrigation system in 1881. It had a population of about 11,000. In 1892, the average daily flow was 1.85 MGD and the system used less than 140 acres. This was the first large scale U.S. sewage farm, and it is important from the standpoint that the designers recognized the principle of providing filter areas for surplus sewage not needed for the best results in crop irrigation.

The Pullman system received a considerable amount of attention. Visitors reported a considerable amount of raw sewage by-passing during cold weather into Lake Calumet (Rafter, 1899). This raised public health questions since Lake Calumet's rice was used by the people of Chicago. It was also noted that the soil of the Pullman system was about 1 foot deep and this was underlain with a clay subsoil.

Around the turn of the century the system at Pullman, Illinois, failed in what was termed a "spectacular" manner (Babbitt, 1947) and land treatment had definitely shifted from being the optimum technology to a less desirable alternative. Several reasons appeared to be responsible for this change in attitudes at this time, with the technical reasons of secondary importance. The older systems in Europe had increasing population loads on them and in many cases there was no opportunity for them to increase the size of the sewage farms. The first English sewage farm at Rugby, England, which had operated since 1853 was converted to biological filtration in 1909. The effects of increased loadings on system performance will be discussed later in this report.

These examples of changing systems and concepts led U.S. engineers to question the effectiveness of land treatment technology. Rafter and Baker (1894) suggested that land treatment would be too expensive and, therefore, unpopular in the U.S. because of the high labor costs. Because of this they suggested that it would be useful at institutions where cheap labor was available. It is doubtful that this suggestion led many to consider this alternative. By 1897 Rafter had changed his philosophy and felt strongly that land treatment would be successfully adopted in the U.S.

It is unclear why labor intensive questions arose at this time since no other reference of this day identifies this as a major issue. The main problem stated by many, was that land treatment systems required careful and continuous management. The English system at Aldershop became famous as an example of poor management when it was only managed for crop production, and Colonel Jones took it over and turned it into a good example of wastewater treatment (Birch, 1879).

Another limiting factor was the influence of cold weather. It was stated that the technology would not be suitable except in the southwestern U.S., thus eliminating most of the area where the population was distributed (Rafter and Baker, 1894; Metcalf and Eddy, 1930). In 1899 Rafter noted that no problem with cold weather would be experienced as long as the temperature did not average less than 32°F. A line between Boston and Portland, Maine denoted the northern limit for sewage farming according to Rafter (1897).

The period between 1900 and 1920 was an ambivalent period for land treatment techology. In 1926 the following confusing statements were made by Fuller and McClintock (1926):

> *"Under favorable conditions sewage filtered through the material of a sewage farm represents the highest degree of purity that is feasible to obtain ...*
>
> *Land treatment can rarely, if ever, compete with other methods now available for sewage disposal ...*
>
> *In summary, therefore, it is fair to state that broad irrigation or sewage farming is likely to be largely superseded by more modern methods of sewage treatment in most cases."*

The above quote reflects several major shifts in philosophy. The obvious is that land treatment was no longer favored or even thought to be a viable alternative for the future. Perhaps more important in relation to the future of the technology is the shift to the concern for sewage "disposal" and the concept that other processes are more desirable even though they are less efficient in purifying the wastewaters. At this time, one of the primary attractive features of competing processes such as activated sludge (developed in 1914) was that it could be used to produce partially treated effluents (Slater, 1888).

The desire to produce only partially treated wastewaters for discharge was a reflection of the development of the legal-political concerns of the time. However, several other technological developments probably had as strong an impact on the changing role of land treatment as any. These relate to bacteria and its role in wastewater treatment, disease and water supply treatment. These will be discussed in some detail later.

Hutchins (1939) reviewed sewage irrigation practices in the western states for the U.S. Department of Agriculture (U.S.D.A.) in order to determine the existing practice and whether it should be promoted. He reported on 125 municipalities that were recycling domestic sewage back to the land. From 1934 to 1937, 11 communities discontinued the use of sewage in agriculture, primarily because of poor soil characteristics, insufficient water volume to supply the demand, or insufficient available land. In general, this U.S.D.A. bulletin was positive towards the use of sewage in agriculture.

An interesting follow-up study was provided to the Hutchins survey by Pound and Crites (1973, Appendix B). They surveyed the same sites to determine those which had ceased or changed their operation. In 1973, nearly 40 years after the Hutchins survey, 84 percent of the systems that were operating in 1937 were still in operation. Most of those that had ceased operation did so because of population growth and expansion around the land treatment areas.

Land treatment systems continued to be built but at a slow rate between 1920 and 1960 in the U.S. By 1964 it was estimated that there were about 2,200 land treatment systems in use (Hill, et al., 1964). These were divided among the categories as shown in Table 1. Thomas (1973) summarized the data on the number of places using land treatment of wastewater from 1940 to 1972. The data shown in Figure 2 on page 7 includes this information. As noted by Thomas, there is no single source of data which records the total number of land treatment systems in use. This is primarily due to the number of different groups involved in pollution control. Many small communities, private industries, especially food processors, and others utilize land application of wastes. Although the U.S. E.P.A. is the primary source for funding of wastewater facilities, today the Farmers Home Administration (F.H.A.) provides grants and loans to a

TABLE 1. NUMBER AND TYPES OF THE 2,192 LAND TREATMENT SYSTEMS REPORTED IN USE IN 1964 (Hill, Bendixen, and Robeck, 1964).

Distribution According to Wastewater Handled

Type Wastewater	Number of System
Domestic	914
Food Products	844
Petroleum	179
Miscellaneous	255

Distribution According to Wastewater Application Method

Method or Place Applied	Number of System
Surface	546
Irrigation	367
Subsurface	702
Miscellaneous	417

significant number of small communities who often choose land treatment technology. The F.H.A. was given responsibility of funding water supply and wastewater treatment facilities in rural communities in P.L.89-240 passed in October, 1965. They are presently bound by the definition of rural places as given by the Rural Development Act which raised the maximum population to 10,000 in 1972. The total amount of wastewater facility support allocated since inception of this program is $1.3 billion, affecting nearly 6000 projects (Calhoun,1977). The average individual grant was for $389,310 in the 1976 fiscal year. Many of these 6000 projects would involve land treatment systems.

The present distribution of authority between E.P.A. and F.H.A. has caused some problems in implementing land treatment technology. E.P.A. has a three-step design and construct payment procedure. They provide for payment to engineers at the end of step one for the infiltration-inflow analysis, environmental impact statements or assessments and a study of the regional design approaches that might be used to solve the waste treatment problem. The second step involves the preparation of final plans, specifications, and contract documents. The third deals with the development and construction of the actual facility. Often F.H.A. is brought into the decision making process after step one or two has been completed. Even if land treatment has not been adequately investigated, the investment of several years effort makes it prohibitive to reconsider the issue of land treatment. A recommendation to include a representative of F.H.A. in step one is among several made by Seabrook (1977 - see Appendix G) to increase the efficiency of delivery of this technology.

A recent attempt to estimate the number of land treatment systems presently in use (excluding individual septic tanks) is shown in Table 2. The approximate number of 3400 indicates that between 10 and 20 percent of all treatment systems in the U.S. are land treatment systems. Estimates of existing facilities that have proposed changes to land treatment and projections for the use of the technology in the future shows that the fraction beginning to consider using land treatment is increasing (see Table 3). Although the projections for future use would increase the number of land treatment systems by about 50 percent, a much larger increase will occur if the recent E.P.A. memo (Costle, 1977) achieves its intended objective.

TABLE 2. ESTIMATE OF THE TOTAL NUMBER OF LAND TREATMENT SYSTEMS PRESENTLY OPERATING IN THE U.S., EXCLUDING INDIVIDUAL SEPTIC TANKS

Publically Owned Facilities Financed by E.P.A. - P.L.84-660*		60
Publically Owned Facilities Financed by E.P.A. - P.L.92-500		300
Publically Owned Facilities Financed by F.H.A. - P.L.89-240		1,600
Publically Owned Facilities Built Without Federal Grants**		250
Private Systems for Privately Owned Housing		50
Private Industrial Systems		1,200
	Total	3,410

*Facility equipment only eligible for support under PL84-660. The cost of land was not supported by this grant in facilities such as the large facility constructed at Muskegon, Michigan.

**Many of these were included in the review in reference Sullivan, et al., 1973.

TABLE 3. PROJECTED NUMBER OF LAND TREATMENT SYSTEMS EITHER UNDER CONSTRUCTION OR IN PLANNING STAGES (Thomas, 1977).

Status	Total Number	Number Identified as Land Treatment	Information Source
Facilities being built or upgraded	2500	250	EPA Grants Program
Proposed for future construction or upgrading	8000	1400	1976 Facilities Needs Survey

The above survey includes the 100+ systems documented by the American Public Works Association (Sullivan, 1973). This survey of U.S. systems is an important reference because it documents the fact that this technology was in use in many places throughout the U.S. in 1972, and that it was highly reliable and a good treatment alternative. The approximate location of U.S. systems, mentioned in the literature, are shown in Figure 3. This data illustrates that the systems are distributed throughout the U.S.

The beginning of the renewal of interest in land treatment in the U.S. occurred in the late 1950's as a result of a growing concern over availability of water resources. Desalination using brackish and salt water was under investigation as was the topic of reclamation and recycle of wastewaters. Decreasing groundwater levels, salt water intrusion and growth limited by the availability of high quality water were common problems, especially in the arid western regions of the country. Since more than 15 million septic tanks were in use, treating a flow of more than 3 billion gallons per day, it was clear that the soil had a significant pollutant assimilation capacity, but that it was poorly defined, thus, long-term definitive studies for reclamation and recycle of wastewaters were initiated by the University of California at Berkeley and the University of Southern California at Los Angeles to more clearly identify limiting parameters. Several studies concentrated on the hydraulic capacities and bacterial removal properties of soil systems when sewage was surface applied (Orlob and Butler, 1955; Gotaas, et al., 1955). This data showed that five California soils could accept 0.5 to 1 foot per day of wastewater, and that bacterial removal occurred in the first few feet of soil. One of the classic publications from this group emphasizes that the soil is a treatment system, and if understood, could be used to effectively control pollutants (McGauhey, et al., 1966).

The California State Water Pollution Control Board has sponsored research on wastewater reclamation and utilization since its activation in 1950. The first project conducted by the University of Southern California concerned underground recharge by sewage spreading (State Water Pollution Control Board, California, 1953). Subsequent studies focused on such topics as groundwater recharge potential from sewage, pretreatment needs, recreational

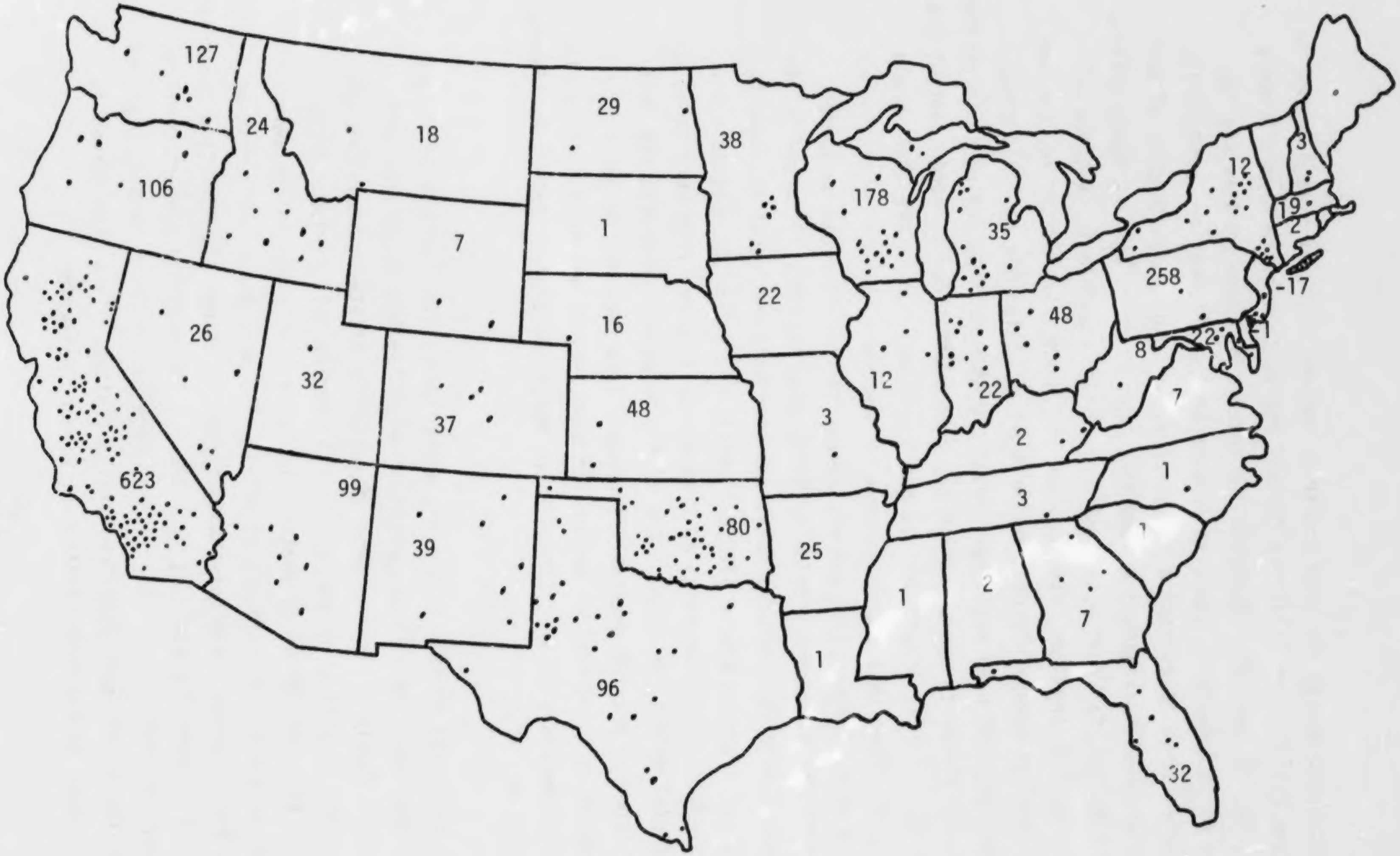
127
24
18
29
38
106
1
7
178
35
12
19
2
3
258
-17
26
22
16
48
32
12
22
8
22
-1
37
48
3
2
7
623
99
39
80
3
1
25
1
96
1
2
7
1
32

Figure 3. Location of land treatment sites in the U.S. cited in the literature are denoted by dots and the total numbers per state indicated by numbers are from Hill *et al*., (1964).

use of reclaimed sewage (on golf courses), and recycling of sewage sludge in agriculture (State Water Pollution Control Board, California Report Numbers 6, 9, 11, 12, 15, and 18). Although the results of these studies are too extensive to include here, examples of some of the findings of these large scale studies serve to emphasize the advanced state of understanding of the soil as a wastewater treatment system more than 20 years ago. A demonstration in Talbert Valley, California, showed that it was possible for a group of private farmers to organize, finance, and construct a wastewater reclamation system to utilize sewage effluent for economical irrigation of field crops. Several golf courses used reclaimed sewage and showed that planning could control all problems related to odors, corrosion, chlorination for pathogen control and soil salinity. Public acceptance was not a problem. In several full scale studies it was shown that simple wastewater treatment systems consisting of algal ponds would adequately treat raw sewage so that it could be surface spread without problems and provide drinking water quality recharged to the groundwater. Large scale sludge recycling studies showed that it would be cheaper to use digested sewage sludge in agriculture than to produce a dry sludge. Sludge application rates as high as 100 tons per acre were found to have beneficial effects on crops. One of the primary conclusions was that: "A sewage farm can provide necessary secondary treatment and disposal of an amenable waste in an economical manner, or even provide the municipality with a substantial monetary return" (State Water Pollution Control Board, California, 1955 - Report No. 12).

It is difficult to explain why the above impressive findings in the mid 1950's did not cause the sanitary engineering profession to utilize land treatment more widely. The discharge of partially treated wastewaters was the most common objective in most of the U.S. during this period. There was probably also concern as to whether the results obtained in the warm arid areas would apply to cold wet climates. The well known studies begun in 1964 by Pennsylvania State University served to answer the questions regarding the impact of climate (Parizak, et al., 1967). The positive support provided by the promotion which the "living filter" received in these studies provided the needed link to the past land treatment activites. This link served to create confidence in the safe adoption of sewage irrigation.

Another major step that occurred in the renewal of this technology was the construction of the large regional Muskegon, Michigan treatment system. This example served to illustrate that the technology could be successfully implemented on a large scale to meet the goals of P.L.92-500.

An important influence on the re-emerging technology of land treatment occurred as a result of the academic influence. The major engineering textbooks reflect trends and also establish them. Perhaps the most popular sanitary engineering textbooks of the early 1900's were those published by the consulting engineering firm of Metcalf and Eddy (1914). In the last edition in which sewage treatment by land was discussed (1930), it was not presented in a favorable light. Land application of wastes was called a "disposal" method because it "is an uncontrolled natural process" and, therefore, was to be classified in the same area as the purification that occurs in discharges or disposal to streams. Sewage farming up to this time had not been adopted on a large scale in the U.S. even though it had been applied to flows up to 570 MGD (4570 MGD during rain season) in other parts of the world (Mexico City, reported by Seabrook, 1972) and sewage farms of 50,000 acres or more were established in other areas.

Few if any students in wastewater control technology had access to texts on land treatment during the period from 1950 through the present. Conspicuous in its absence was any mention of land treatment in Fair and Geyer's well known text, Water Supply and Wastewater Disposal (1954).

PROMINENT FACTORS INDIRECTLY RELATED TO DEVELOPMENT OF LAND TREATMENT

The previous section attempts to briefly summarize the history of land treatment without providing much background as to why certain changes took place. In reality it is impossible to separate the technical developments in one area from those in closely related areas, or to interpret isolated events without including background in the political and social areas in relation to the technology. This section will be used to attempt to weave into the history of land application of wastes, the major peripheral events and understanding which appear to be significant in shaping the fate of land treatment technology.

LEGAL ACTIVITIES - BRITAIN

Almost all the legislation affecting land treatment up to about 1872 was enacted by British authorities. The earliest statute on water pollution appears to be one of 1388 which prohibited the throwing of dung, filth, and garbage into ditches, rivers or other waters of nearby towns. A Bill of Sewers was passed in 1531 empowering the Crown to establish commissioners. This bill was not replaced until the Land Drainage Act of 1930. Another bill passed in 1535 provided that "a penalty of one hundred shillings should be paid by any person annoying the Thames or casting dung into that river" (Ardern, 1977). The beginning of sanitary science was marked by the 1844, "Health of Towns Commission Report." This provided a written record of the nuisances that existed at this time. The problem of sewers backing up into the basements of cities where sewer discharges to tidal areas was felt to be a health hazard, as was the deposits of fecal matter on the streets. "In some cases, whole towns deposited their wastes on the streets, even from the second story windows or balconies." "Out shot closets" or toilets with pipes leading directly to ditches or streams were common at this time. It is easy to understand why Chadwick proposed his "arterial system of drainage" in order to correct these types of problems.

In 1847 the British Towns Improvement Clauses Act first recognized land treatment as a means of dealing with sewage. It should be remembered that this was a time period of the great epidemics, when the death rate of various cities soared up as high as 100 per 1000 population. In 1855 the Nuisance Removal Act was enacted to provide local authorities with the power to order individuals, industries, or whole villages to clean up, to be able to designate some authority to do it for them and to force the offenders to pay for the costs of doing it. In 1865 the Commission on Towns Sewage Disposal stated that "land application was the only way to avoid river pollution and make a profit." At this time some towns were convinced that a profit could be made in sewage farming and cancelled agreements with farmers and started city owned operations.

The Sewage Utilization Acts of 1865 and 1867 prohibited construction of sewers that might have a direct discharge into rivers or ocean where a nuisance could be created. This legislation provided for the acquisition of land and the construction of sewage works. In 1868 the British Association on the Treatment and Utilization of Sewage produced the first comprehensive report on this topic.

The first Royal Rivers Pollution Commission published their first comprehensive report in 1872, and provided a great deal of information on the role of land application of waste. This report was significant since it produced among other things recommendations for the quality of effluents that could be discharged to rivers. The recommended discharge standards published in this report are reproduced in Table 4 along with another set of standards established for the Thames River. It is interesting to compare these standards developed more than 100 years ago to those promulgated as a result of P.L.92-500. Several parameters, such as suspended solids are the same. The fact that these standards were ahead of their time is reflected by the fact that they were first adopted by the government in power when they were recommended and then rejected by the next government. They were not used after that except as a reference to effluent quality which was difficult to acheive by treatment processes other than land treatment (Slater, 1888).

TABLE 4. SUMMARY OF THE FIRST SEWAGE EFFLUENT DISCHARGE STANDARDS WHICH WERE DEVELOPED IN ENGLAND (Denton, 1877)

A. River Discharge Standards - Conservation of the River Thames

1. It should be free from an offensive odor.
2. It should be free from suspended matters, or in other words, be perfectly clear.
3. It should not be alkaline to tumeric - paper or acid to litmus paper.
4. It should not contain per gallon more than 60 grains of solid matter dried at 260°F.
5. It should not contain more than three quarters of a grain of organic and ammoniacal nitrogen per gallon.
6. It should not contain more than two grains of organic carbon per gallon.
7. It should contain not less than one cubic unit of free oxygen in a gallon.

B. Standards suggested by the Rivers Pollution Commission

1. Any liquid containing in suspension more than three parts by weight dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.
2. Any liquid containing in solution more than two parts by weight of organic carbon, or 0.3 part by weight of organic nitrogen in 100,000 parts by weight.
3. Any liquid shall exhibit by daylight a distinct colour when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.
4. Any liquid which contains in solution, in 100,000 parts by weight, more than two parts by weight ofany metal except calcium, magnesium, potassium, and sodium.
5. Any liquid which, in 100,000 parts by weight, contains whether in solution or suspension, in chemical combination or otherwise, more 0.05 parts by weight of metallic arsenic.
6. Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition either of sulphuretted hydrogen or of a soluble sulphuret.
7. Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 100 parts by weight of distilled water.
8. Any liquid possessing an alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

Although the discharge standards shown in Table 1 could not be achieved by unit processes available in 1872 (mainly chemical precipitation), the well operated sewage farms could easily meet these standards of water quality in water discharged from the underdrains of the fields. The importance of these standards was not in their influence in the application of the technology, but in suggesting that partially treated wastewaters with some solids and color could be safely discharged to rivers. Essentially this established the background philosophy which indicated that any technology which could achieve these standards in an easier or less expensive manner than sewage farming would be capable of producing a dischargeable effluent. It would appear that these standards assisted in providing the early thinking necessary for adoption of processes less efficient than the land treatment that were used 30 years hence.

Slater (1888) noted that these standards had been persistently "obtruded upon the public" and that they were nearly adopted in the Sewage Bill of 1887. He criticizes the standards by noting that they raised the possibility of a manufacturer withdrawing enough river water to dilute its effluent to obtain the required concentration; and therefore, indicates that all standards based on concentration are "fundamentally and essentially absurd." Slater goes on to comment that; "It is therefore, I submit, the duty of the public to dismiss them (the standards) as impracticable, unpractical, and even dangerous, and to propose some simpler standards, less elaborate, and turning less on disputable analyses."

It appears that the discussion of various techniques of sewage treatment had reached an intensive level by 1888. Slater (1888) notes that, "Unfortunately there is no subject, outside the range of party politics, on which so much envy, hatred, malice, and all uncharitableness prevail as on the treatment of sewage. But I ask people to judge by the evidence of their own senses. Do not read about this or that process, but go and look. I know instances where bitter enemies of chemical processes have been convinced of their error by just one unexpected and unprepared for visit of inspection."

According to the timing, the number of attendees, and the topics discussed, it appears that the most significant meeting in the history of sanitary engineering took place in 1876 at the Conference on the Health and Sewage of Towns sponsored by the Society of Arts in England. Speakers included Col. Jones, Latham, Birch, Marham, Franklin, Dupre, Dewar, and Dibdin, many of whom had written or were in the process of writing texts on sewage treatment and disposal. This meeting provided a forum to discuss various processes and sewage works. According to Slater (1888), "irrigationists, and filtrationists led the discussion at this meeting, but room was left for the friends of precipitation as rationally conducted with the aid of absorbents.[1]"

The Rivers Pollution Prevention Act of 1876 was a mild measure which was considered to be a failure because it was not enforced (Slater, 1888). It did not fix any standards for discharge and it ignored completely the earlier Royal Commission recommendations. Further, it attempted to protect the existing municipalities and industries by making them exempt from the regulations. Another omission from this legislation was the lack of any concern regarding the status of groundwater.

In 1884 the second report of the England Royal Commission on Metropolitan Sewage Discharge indicated that most authorities were "strongly and unanimously in favor of land treatment." This was an influential stand because it provided the authoritative basis for all town local boards to require that adequate land be purchased in all cases of sewage treatment where public financing was to be involved. From this time until 1901, all instances of sewage treatment facility construction were required to purchase enough land to incorporate land treatment, even if the town was adopting a discharge technology. In 1901 the Local Government Board allowed financing of a sewage treatment system at Newcastle-Under-Lyme without the purchase of land for the first time since the 1884 report (Stanbridge, 1976).

Because of the increasing debates surrounding the proper sewage treatment technology, the Royal Commission on Sewage Disposal was asked to determine whether the new methods of treatment would be efficient enough to allow discharge around the turn of the century. In 1901 the Commission reported that land treatment was "impractical in some cases, and that artificially treated wastewaters could be discharged."

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[1] Slater was referring to process such as the ABC process in which the letters stand for alum, blood, and clay. The alum acted as the precipitant while dried blood and clay were thought to be the absorbents. The product sludge was sold as a high quality fertilizer.

By 1912 the Royal Commission on Sewage Disposal had adopted effluent standards which included a BOD and suspended solids of 20 mg/ℓ. Complete treatment was considered to be technology which would meet these standards. Therefore, it is clear that the legislative history of Britain made it possible and probably preferable to convert from land treatment to partial treatment and discharge.

LEGAL ACTIVITIES - U.S.

Complete purification of wastewaters was not a goal of U.S. legislation and sewage treatment activities until 1972. Early sewage legislation and research was conducted by the states. Perhaps the concepts of natural stream purification and dilution as a solution to pollution was most prominent since local pressures were mainly responsible for control measures. Collection of information on U.S. sewage practice was initiated when the Massachusetts legislature requested that the Massachusetts Board of Health review the topic on April 16, 1872 (Rafter and Baker, 1894). In 1876 the 4th Board of Health Report states that there "is no better recepticle than the ocean for the sewage."

In 1884 there was considerable concern that industry should be given special privileges to develop, and the Mill Acts grew out of this concern. Although this legislation was not intended to affect sewage treatment it was responsible for establishing the "Principle of Permissive Pollution" in which industries were allowed to use the streams and rivers as sewers so that they could continue to develop and benefit the community without being inhibited with the cost or inconvenience of wastewater pollution control (Rafter and Baker, 1899; Metcalf and Eddy, 1930).

The principle of natural stream purification had been under study for some time when the Massachusetts legislature passed a law which stated that

20 miles of passage of raw sewage in a flowing stream will purify it so that it can be used as a drinking water source around 1890 (Rafter and Baker, 1894). At about this same time a New Jersey Court held that sewage from 15,000 could be directly discharged raw into a river where it received a dilution of at least 80:1, flow 4 miles and safely enter the water supply of a population of 400,000 people.

Dilution as a solution to pollution has long been considered as a major philosophy of wastewater control. In 1894 the minimum dilution required was thought to be 10:1 and usually it was taken to be greater than 50:1 (Rafter and Baker, 1894). The British Royal Commission on Sewage Disposal Report of 1912 recommended a dilution of 500:1. In 1930 the U.S. rule of thumb was to use a dilution of 100:1 for the discharge of raw sewage (Metcalf and Eddy, 1930).

The above discussion of early legislation on water pollution control in the U.S. should not be taken to mean that there was little concern over pollution. In fact, there was great concern and activity in this area. However, the distribution of the population and the availability of large quantities of water in proximity to most of the population decreased the urgency of the problem. It should also be noted that this period was when the germ theory was becoming well accepted (1890) and also much debate was occurring in Europe over the most desirable waste treatment process.

In 1914 fifteen prominent sanitary engineers were commissioned to establish drinking water quality standards. Since the branch of government in charge of the development was in the U.S. Treasury, these were first called the Treasury standards. They later formed the basis for the development of National standards when in 1974 Congress passed the first comprehensive safe drinking Water Act (P.L.93-523). The passage of this law is important in regards to land treatment since EPA had little authority over wastewater discharges to the groundwater prior to the passage of this bill. The Drinking Water standards provide clearly defined water quality criteria and land treatment systems must be able to ensure that the groundwater under land treatment sites can continue to meet these standards if the groundwater is presently being used as a source of drinking water, or if it is a potential source. Land treatment systems are allowed to have groundwater quality less than drinking water in cases where it is agreed that it is not a potential drinking water source. The EPA regional administrators assist in developing the level of treatment standards for these sites.

The Federal Water Pollution Control Act of 1956 (P.L.84-660) was the first law to provide Federal funding for publicly owned sewage plants (Seabrook, 1975). However, funding support was limited to the treatment system and did not include cost of land. Equipment purchased for wastewater treatment at the Muskegon land treatment system received support under this law.

Considerable emphasis was placed on the definition of stream assimilation capacities and the optimum use of dissolved oxygen resources in streams from the 1950's to the early 1970's. A Nationwide effort to classify streams according to their optimum use and to prescribe only the required partial treatment required to meet the stream standard into which the wastewater was discharged was the main focus of wastewater treatment during this period. This responsibility for classification of all streams and rivers was carried out by the state pollution control organizations. The activity in this area in these two decades is far too voluminous to include here. However, more activity surrounded the attempt to classify streams and to determine optimum usage and the amount of pollutants that they could safely assimilate than any other single task in pollution control in the U.S. In light of this commitment it is clear that any legislation which rejected the concept of using a fraction of the self-purifying capacities of streams for pollution control and replace it with the goal of "non degradation from natural background conditions" was bound to be met with strong resistance by the technical community.

Eutrophication became a major pollution control issue in the 1960's. The pollution of surface waters with inorganic nutrients that triggered undesirable natural plant growth caused a number of things to happen which, although they were indirectly related to land treatment, may have been the key forces in changing the pollution control laws. For the first time since discharge of partially treated wastewaters was thought to be acceptable, the public became impressed with the concept that the conventional approach to pollution control was still causing visible degradation of surface waters. The emphasis on phosphorus resulted in the passage of state laws banning (or severely limiting) the phosphorus content of detergents. The competition generated by the detergent industry in producing and marketing clean detergents served to emphasize the National interest in a clean environment. The eutrophication issue served as a vehicle to make ecology and water pollution a household topic of conversation and assisted in setting the stage for the change sought by P.L.92-500.

The well known plan which has been called the "Zero Discharge" law, P.L.92-500, was extensive amendments to the Federal Water Pollution Control Act of 1956. The goal of this bill was to eliminate wastewater discharges, but this was to be accomplished with best practicable and economically feasible techniques. Since land treatment was used very little, it was rarely, if ever, recommended as the best practicable technology in the years following the passage of this law, even though the bill clearly indicated that the option of land treatment should be carefully evaluated in all cases.

It is probably fair to say that this bill created more controversy within the engineering profession than any other water pollution control bill. At the time of passage of the bill the average environmental engineer (the sanitary engineer changed his name around 1972) knew little, if anything, about land treatment. Conversely, few agriculturalists knew very much about the use of sewage in crop production. Thus there was considerable reluctance within the engineering profession to give land treatment processes equal status with other established technologies. It should be pointed out that by 1972 there were a considerable number of environmental engineers who were well educated and trained in numerous bioloigcal, chemical, and physical treatment process technologies, so the addition of land treatment as an additional option had little appeal in terms of making pollution control technology more effective--particularly in light of the little training which was received in this area. Thus, in 1974 EPA issued a special memorandum to its regions to avoid approving any new installations until the land treatment option had been sufficiently evaluated (Seabrook, 1975). As was noted earlier, this has recently been followed by a strong statement which will require land treatment processes to be evaluated in all circumstances (Costle, 1977).

Because of the lack of modern experience with land treatment, many states, faced with establishing guidelines for evaluating the option of land treatment, established highly restrictive guidelines. Morris and Jewell (1973) noted that:

> *"State governments frequently legislate regulations above and beyond those promulgated by the federal governments. But state laws rarely become so strict that they jeopardize a federal mandate. This is, however, the situation that appears to be evolving in the area of land application of wastes."*

In a 50 state survey of guidelines established for setting up land treatment systems, most of the states with regulations (31 either had regulations or were developing them) specified significant pretreatment requirements, application rates, and type of land that would be required for land treatment (Morris and Jewell, 1977). The varied state and local requirements for the amount of treatment prior to land application is of particular concern. Quite often these requirements are not consistent with the known capabilities of soils to control pollutants. This approach appears to be prevalent because the authorities responsible for guidline development consider that application of wastes to land is a disposal operation rather than use of a treatment system. The authority of states to regulate discharges to the environment has resulted in a misinterpretation of Section 510 of P.L.92-500. The state treatment requirements prior to land application assume that the soil has no renovation capability. Since the land that is "an integral part of the treatment process" is eligible for federal financial assistance under P.L.92-500, it is by definition a component in the treatment process. Standards and other requirements by state and local regulatory agencies should apply to the final effluent from the land treatment process, and not at some internal point in the process, such as the secondary effluent quality requirement prior to land application.

Some state agencies, notably California, that have had extensive experience with recycling and reclamation of wastewater by land application, have regulations which encompass proven technologies. California's regulations for land treatment systems are based on the end use of the products produced on the sites rather than on the internal process characteristics. Their guidelines might be considered for adoption by EPA in order to provide uniform national guides. In many instances land treatment would be disqualified as a cost-effective alternative by the EPA's criteria if the state guidelines were followed. This would make federal support unavailable for construction of a land treatment system since it was required that the funded alternative be considered best practicable technology and cost effective. Costle's memo (1977) indicates that if these state requirements remain in effect, some portion of federal funds will be withheld from the project.

The final legislative developments which affect land treatment relates to the portions of the system which qualified for federal support. Up until recently the cost of the land was not included in federal support for construction of the treatment system. This has now been changed and the land where the waste is applied is eligible for federal support at the 75 percent funding level. This is also true for sludge application sites.

Passage of P.L.95-217 in December, 1977, expanded the eligible category for acquisition of land to include the land that will be used for storage of treated wastewater in land treatment systems prior to land application.

TECHNOLOGICAL AND PUBLIC HEALTH ISSUES

TREATMENT REQUIREMENTS AND PUBLIC HEALTH

The remaining factors which appear to be primarily responsible for the changing status of land treatment relate to key technological developments, the definition of efficiency of wastewater treatment, and public health. In many cases the occurrence of epidemics appeared to be responsible for motivating large cities to incorporate sewers and sewage treatment. The bacteria responsible for the most common water borne disease, typhoid, was discovered in 1880 by Eberth. It was also about this time that a clearer understanding of the germ theory and its relation to water and treatment processes developed. The relationship of these events to the development of public water supplies and deaths attributable to typhoid is illustrated in Figure 4.

As late as 1888 the role of bacteria was very poorly understood. Slater (1880) notes that:

> *"As regards 'germs' or morbific ferments, it is now generally held that these tiny organisms when introduced into the system are not the direct cause of disease and death, but that they generate within the body they invade certain most intense poisons, which do the deadly work."*

P.F. Frankland first defined the capability of the intermittent filter to remove bacteria in 1887 (Rafter and Baker, 1894). Thus it was not surprising that sand filteration was applied to water supply systems for bacteria control shortly after this time. The first large scale water supply slow sand filter was installed at Albany, New York in 1899. This was an impressive 15 MGD facility. The first rapid sand filter was constructed at Little Falls, New Jersey in 1901.

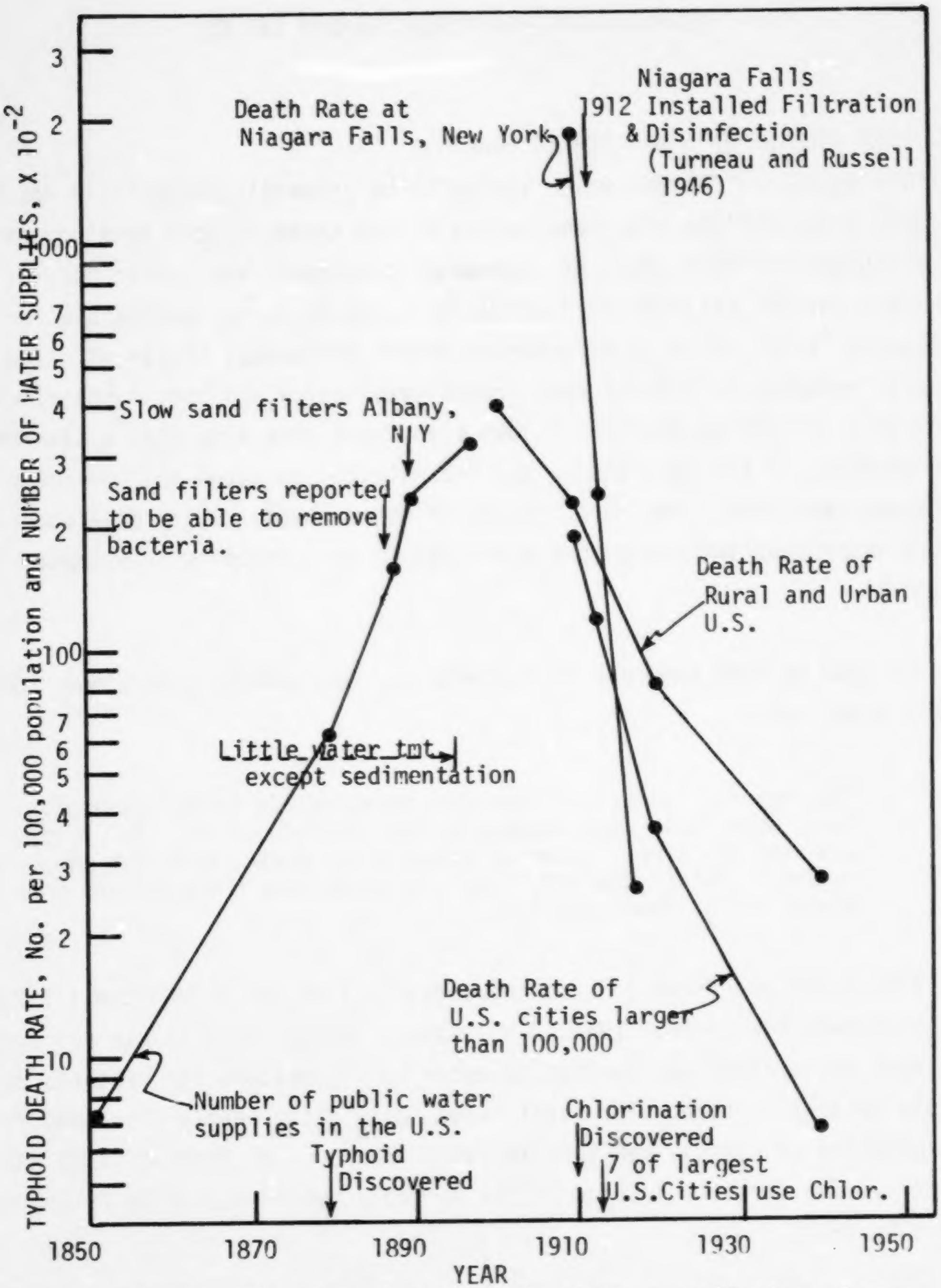

Figure 4. Relationship of deaths due to typhoid, installation of water supplies and related technology.

Throughout the controversy of sewage treatment between 1870 and 1890, it had been argued by some that it was much less expensive to treat the water before using it as a water supply rather than to treat the wastewater prior to discharge into a receiving water. Identification of the cause of disease and efficient technology to control it in water supplies essentially eliminated the need for efficient wastewater treatment.

The addition of a disinfectant to the water supply was the final requirement needed to provide pathogen free drinking water under most conditions. Bleaching power was first applied to drinking water on a continuous basis in 1908. In 1910 liquid chlorine replaced the bleaching powder, and by 1913, 7 of the 12 largest cities in the U.S. were using chlorination. The drastic decline in deaths due to typhoid (Figure 4) was a reflection of the effectiveness of filtration combined with chlorine to control the pathogen content of water supplies.

In 1894 it was noted that intermittent filtration of raw sewage with sharp, clean coarse sand filters resulted in 99.9 percent bacterial removal at a filter loading rate of 60,000 gallons of raw sewage per acre per day, and nearly complete bacterial removal occurred at application rates of 20,000 to 40,000 gallons per acre per day (Rafter and Baker, 1894). To a large extent, the availability of this technology to water supplies removed the necessity of obtaining extremely high quality water from sewage prior to discharge into receiving waters.

DEFINITION OF WASTEWATER TREATMENT

The early work on sewage purification indicates that a great deal of emphasis was placed on nitrogen and the forms in which it was found in the effluents. In fact, prior to 1890, process efficiencies were usually judged mainly on their capability to remove nitrogen in the "albuminoid" or organic form. The following statement indicates that nitrification was thought to be a fermentation responsible for purifying wastewaters (Rafter and Baker, 1894):

> *"The necessary essential for the resolution of organic matter into more primary forms of matter by the operation of nitrification is that the nitrifying organisms shall be present in conjunction with an alkaline mineral base."*

As shown in Table 1, the forms of nitrogen comprise a major focus of the early effluent standards. Obviously, bacteria removal efficiency was not of concern until about 1890, and neither was soluble organics. It was thought that adequate treatment could be judged on the basis of the completeness of the conversion of the nitrogen to oxidized forms and that this must be related to the organic carbon cycle. In 1887 it was proved that organics and nitrogen were oxidized by living organisms. This removed the mystique that surrounded the effect of burning which was supposed to occur in waste treatment as a direct effect of the presence of oxygen. However, in 1890 Winogradsky showed that certain bacteria could oxidize nitrogen without the need for the presence of organics (Rafter and Baker, 1894). Thus, the discovery of autotrophic nitrifying bacteria must have injected a note of confusion into the discussions surrounding process efficiencies as defined by nitrogen conversions.

POLLUTION REMOVAL EFFICIENCY AND ECONOMICS

The final two issues which are often responsible for changes in technologies are economics and treatment efficiency. Both of these issues are highly complex and can only be briefly treated in this review. The main question of interest is whether land treatment was a competitive process in these two areas. The question of economics has been examined previously. From 1850 to 1880 many thought that land treatment could be a profitable wastewater treatment operation. By 1890 it was clear that this was not the case, but that it still represented a technology which was more cost effective in most instances. In 1877 Denton noted that, "practice of the last 20 years has failed to show that any profit at all is to be obtained from sewage farming."

Several authors noted that revenue from the sale of crops could pay for operation and maintenance of sewage treatment systems but that the income could not cover amortization of the capital investment (Rafter and Baker, 1894; Rideal, 1906; Keefer, 1940). This particular conclusion appears to still hold true for modern land treatment systems, and represents an important economic difference between conventional discharge systems and land treatment systems. Although operation and maintenance costs of modern facilities represents one quarter to one half the total costs, it may represent nearly the total cost for which the local community may be responsible. Thus the land treatment alternative may be highly cost effective where the revenue from crops can be used to offset most of the operating and maintenance costs.

It is difficult to make cost comparisons in the time period in which land treatment was being phased out (1890 to 1910). But no references were found which showed general economic advantages of discharge systems. Keefer (1940) discusses the costs of several types of systems in the early 1930's. Land treatment in use in several cities was significantly less costly than activited sludge or trickling filters. Although the economic arguments are not clear, it does not appear that they played a major role in the shift from land treatment usage.

Teitjen (1977) reported on a cost comparison between the large sewage farm at Braunschweig, Germany (about 40 MGD) and five sewage treatment plants with equivalent populations. The five discharge systems cost, on the average, 18 percent more than this large land treatment system, and the discharge failities achieved average BOD removal efficiency of 87 percent. Because of the nuisance of odors produced by the application of raw sewage, intensive aeration will be installed after sedimentation in the Braunschweig system (Teitjen, 1977).

Other conditions under which land treatment of wastewaters would be competitive at the present with advanced wastewater treatment and discharge have been examined by Pound, Crites and Smith (1975). Several general conclusions which were made from these cost comparisons are as follows (Pound, et al., 1975):

1. Land application systems are less sensitive to economics of scale than advanced wastewater treatment processes, and up to 100 MGD they are more cost effective than phosphorus, nitrogen, and suspended solids removal added to secondary treatment.

2. Under unfavorable conditions (cold and poor soil) the flow rate at which land treatment is more cost effective than advanced treatment occurs only at flows less than 3 MGD. In many instances where conditions are more favorable, land treatment is competitive with conventional secondary treatment (with nitrification) up to a flow rate of 20 MGD. Under good conditions land treatment is cost effective with activated sludge up to 100 MGD.

3. Land treatment would be highly competitive with advanced wastewater treatment in most situations.

4. Because the cost of operation and maintenance are lower for land treatment systems, the local share of total costs of the systems is much smaller than with advanced wastewater treatment discharge facilities.

Today, the issue of cost effective wastewater treatment is closely related to the efficiency question. The 1977 deadline for wastewater treatment requires secondary treatment level efficiencies for all municipalities. This means that the effluent must have a monthly average effluent quality equal to or less than 30 mg/ℓ suspended solids and 30 mg/ℓ BOD_5. Many industries have had their discharge effluent qualities set at standards that can be achieved by secondary treatment. Thus, in general, cost effective treatment technology will often be judged against secondary treatment discharge technology such as activated sludge. Unfortunately, many state laws and guidelines require that this level of treatment be provided before the wastewater is taken to a land treatment system (Morris and Jewell, 1977). In these instances it is impossible for land treatment to be economically competitive with the discharge technology, since it is required as part of the land treatment system.

The question of process efficiency is difficult to analyze over a time period dating back to 1850 with the sewage farms because of the changes that have been made in pollutant definition and measurement techniques. In the early instances it was recognized that if the sewage could be made to flow through 4 to 6 feet of aerated soil, that the effluent would be of a very high quality, and close to drinking water quality. The departure from production of such high quality effluents from the early sewage farms usually represented a failure in a part of the system which was most often brought about by poor management. In effect, most soil systems act as an "all or nothing" type treatment process. As long as they are not overloaded the effluent that can be discharged from underdrains in soil systems is usually of high quality. Furthermore, if the soil temperature remains above freezing and the pH is around neutral it will achieve nearly complete nitrification. Overloading of the soil with water or pollutants will rapidly lead to discharge of almost untreated wastes, and the soil will become clogged and the wastes will become surface runoff. Such failures were fairly common in early systems because they were initially loaded at high rates, and few were able to expand as the sewered population grew around them. Several researchers have stated that the failures of this type were primarily responsible for the demise of the land treatment technology (Stanbridge, 1976; Ardern, 1977; Teitjen, 1977). Systems such as activated sludge that could provide some degree of treatment under heavy fluctuating loads was considered to be superior to one which when overloaded would fail. Failure to perceive the need to incorporate expansion and flexibility in early land treatment may have been responsible for the failure of many early systems.

The changing attitude towards land treatment and the value of sewage is reflected in the following quote from Denton (1870):

> *"It is not possible, however, that although up to this time all chemical processes have practically failed in purifying sewage, so that the effluent fluid may be discharged without injury into rivers, some process may yet be discovered whereby a profitable manure may be prepared out of the bulky and unwieldly matter called "sewage," which may extract from it every particle of matter deleterious to human and productive of vegetable life, and which would be more profitable in an agricultural sense than the sewage itself. This object, however, appears very distant at the present. It is indeed more than possible that even at this moment those substances of organic matter which are extracted from sewage by the partial processes in practice constitute an article more valuable, as a saleable manure, than the whole of sewage from which it was taken - if we adopt as the test of value the return per head of the population contribution the sewage. But this is hardly a proper criterion: for as long as any portion of deleterious or fertilizing matter is retained in the effluent liquid discharged into our rivers, we fail to complete success, short of which we ought not to stop."*

By 1877 the loading rates used at Edinburgh Craigenetinny Meadows exceeded a population equivalent of about 120,000 people per acre (applied value was 2250 m/yr. according to Robinson & Mellis, 1877.) Although this historic sewage farm was reported to be a good example, it was in reality a highly overloaded system which resulted in a highly offensive-smelling swamp that produced a polluted effluent (Stanbridge, 1976). Denton (1877) indicated the the Edinburgh system was carelessly managed and could have resulted in a public health hazard, but "nowhere have we found instance of ill health that are properly attributable to malaria or other causes due to irrigation." In 1868 the doctor of the military camped on the edge of the 200 acre sewage farm noted that although, "the stench in the barracks is sometimes quite sickening," no effect on the health of the troops was observed. The troops were also present when cholera was at epidemic levels in Edinburgh. No cholera was reported in the population around the sewage fields. This was true for several other sites referenced by Denton (1877).

The fact that many systems were probably overloaded by the late 1880's was substantiated by Slater (1888) in which he notes that, "I have never happened to visit or to pass near an irrigation field in warm still weather without detecting an unpleasant odor. At Genneivilliers, near Paris, the odor, in calm autumnal evenings, may, without exaggeration, be described as abominable."

Thus Slater was not an ardent promoter of land treatment and concluded, "I would submit that irrigation, though an excellent method of disposing of, and at the same time utilizing sewage where suitable land is available, where the climate is warm, and the rainfall scanty or intermittent, is not applicable where these conditions are absent."

Some time later in emphasizing that land treatment systems require careful management, Rafter and Baker discuss the common objection to odor as follows (1894):

> *"It has been frequently urged against sewage farms that the fields are likely to become exceedingly offensive. The same is true of neglected barnyards although in the present state of agricultural development no one would seriously propose to abolish all barnyards because of the patent truth, nevertheless it is exactly what is proposed in the case of sewage farms."*

Additional data was discussed by Rafter and Baker (1894) which indicated that good management was capable of controlling odors.

An attempt to summarize the loading rates of land treatment systems over the years is shown in Figure 5. The loading rate at two sewage farms can be compared over a period of 40 years usage at Aldershot and Altrincham, England. In both instances the loading rates nearly doubled due to population expansion without increasing the size of the sewage farms.

Many present state regulations recommend the application of 2 inches per day of secondary treated wastewater in land treatment systems. This would be equivalent to a land treatment population loading of about 100 people per acre if the application sites were allowed to rest for five or six days (assuming a wastewater flow of 100 gallons per person per day). Although the sewage flow in the 1800's was less, the population loading rate with untreated sewage was up to five times higher than the present recommendations. It is clear from this analogy that the systems were heavily loaded and poor management could easily lead to failure of the soil filtering efficiency and could result in what was termed "sewage sickness." It is not surprising that the application of raw sewage created offensive odors in many of these early sewage farms.

The relationship of pretreatment to the loading rate is also illustrated in Figure 5. Although Franklin recommended a loading rate with raw sewage on intermittent sand filters of 2300 people per acre in 1870, the recommendation was decreased to 1000 people per acre in 1880 (Denton, 1885). In 1898 loading rates equal to and exceeding this value were allowed by the authorities, but only with extensive pretreatment. An application rate of 4800 people per acre was acceptable whenever chemical precipitation and biological filtration preceded intermittent filtration.

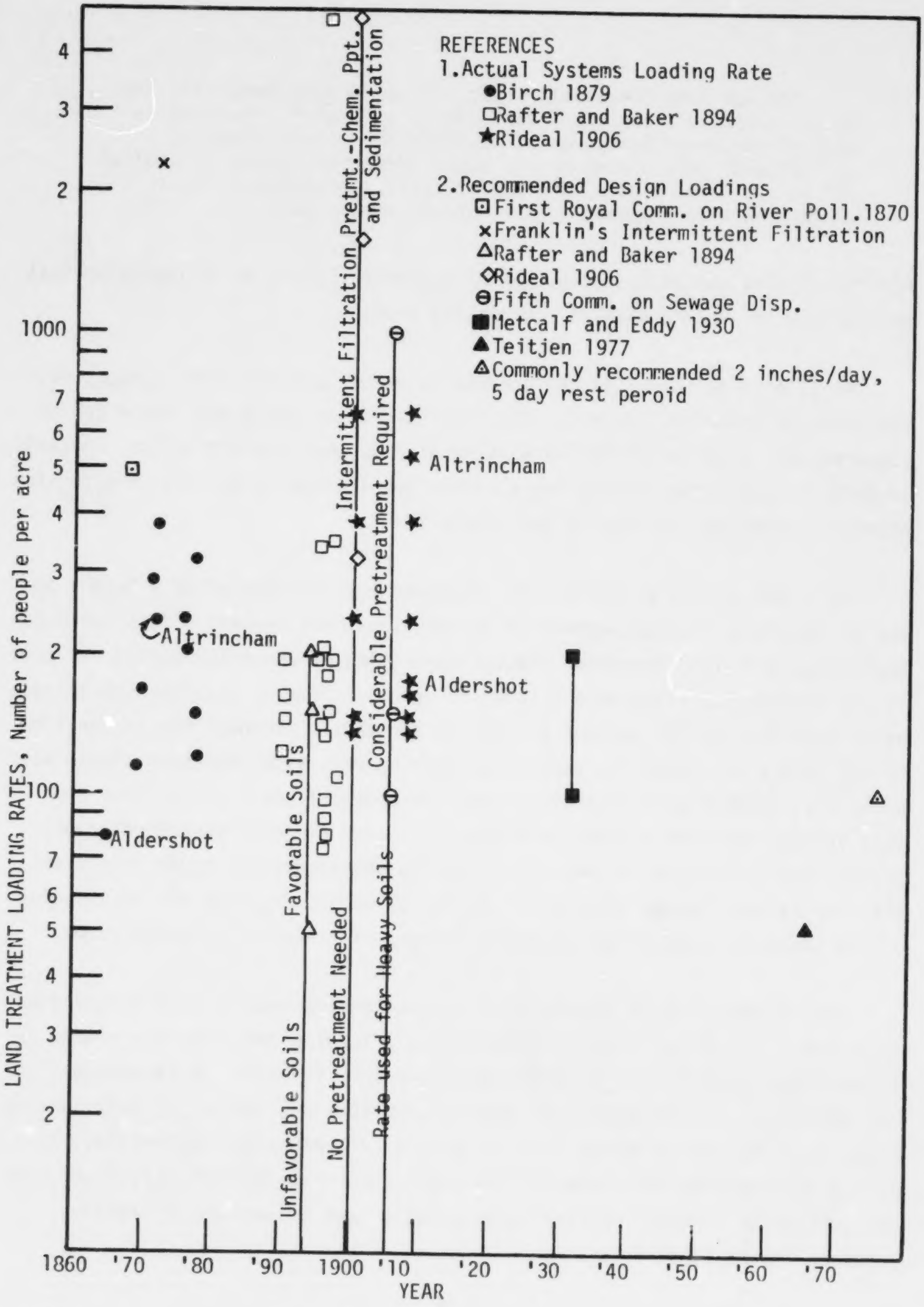

Figure 5. Loading rates for sewage farms, spray irrigation, and intermittent filtration systems.

A comparison of the treatment efficiencies achieved with various processes is summarized in Figure 6. This figure clearly indicates the partial treatment achieved by discharge process and the more complete purification achieved in land treatment.

Detailed considerations of the public health aspects of land treatment technology evolution are beyond the scope of this review. However, this is one of the main issues sited as being of concern to those unfamiliar with the technology. Throughout the review of documents siting the historical aspects the writers found little negative information that showed that land treatment posed an unacceptable health hazard. Many studies indicated that there was no negative impact on the health of the workers or those living on or close to sewage farms. A recent comparison of the relative health effects of discharge and land treatment systems reported has been prepared by Crites and Uiga (1977). They concluded that under comparable conditions, land treatment was more effective in controlling pathogens and other toxic elements.

Two recent developments will assist in the updating of land treatment technology. The E.P.A. recognized the lack of educational material that existed in this area and supported a study at Cornell University to develop a comprehensive educational program beginning in 1975. This project will provide a self-paced, audio-tutorial program which will be available to the public in 1978. In October of 1977, a design manual for land treatment of mubicipal wastewaters was distributed to the public by E.P.A. (U.S. E.P.A., et al., 1977).

Cornell University's one week short course and the design manual were developed so that they would be complimentary. These two items will serve to bring individuals up-to-date on the land treatment technology.

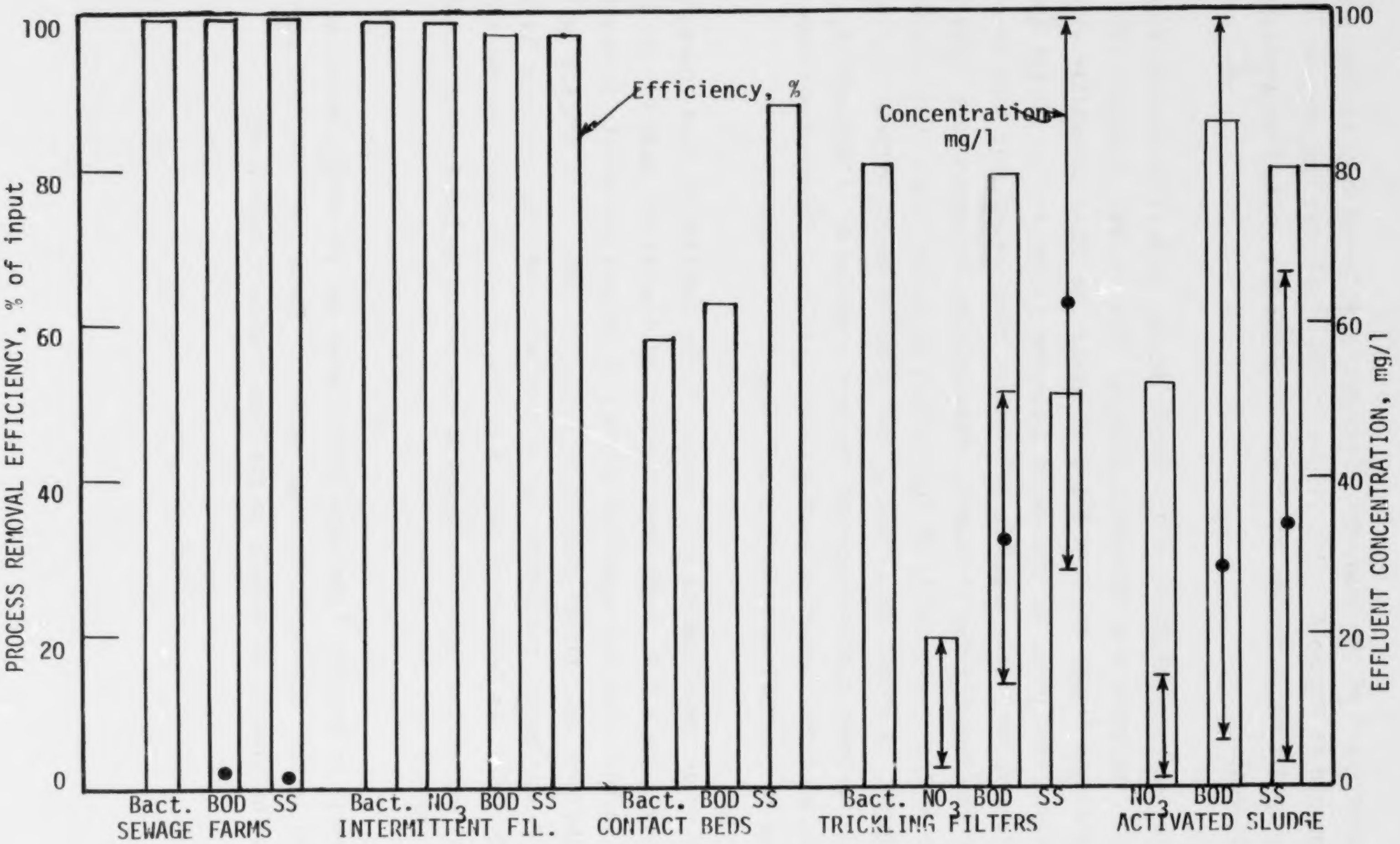

Figure 6 Examples of process efficiency comparisons for the treatment of domestic sewage. Data on unit processes from Keefer (1940). Average effluent concentrations are represented by the dots.

DISCUSSION

The fate of the use of land for waste treatment has been reviewed by others in an attempt to illustrate and document its development throughout different periods of history (Hartman, 1975; Stanbridge, 1976). This brief review of the historical development of this water pollution control option attempts to interweave the major technical, political-social, and legal factors which appear to have influenced the use of land application of wastes. Today, the land treatment of wastewaters is not considered by the general water pollution control field as being the standard by which other approaches should be judged, and it is not even a popular technology. In retrospect, it seems clear as to why this is the case and it would appear to have been predictable in light of the understanding of various aspects of the history of water pollution.

The simple concept of returning the nutrients and other materials which originally came from the land back to land seems to be a valid concept upon which to build a new era of water pollution control in the U.S. At one time in past history this had been a highly successful technology and a number of treatment systems are still effective after more than a half a century of operation. In several cases these treatment systems have been used for nearly a century. More than 3000 land treatment systems are in use for municipal and industrial wastewater treatment. About 10 percent of the new plants and modifications for updating existing plants are committed to land treatment. The obvious question that this review attempts to address is: "If the technology is effective and has been proven, why is it not being adopted at a faster rate today since its consideration is now mandated by law (P.L.92-500)"?

Although large cities have existed for 5000 years, and many large concentrations of populations have existed for the last 1000 years, modern sanitary science is only a little more than 120 years old, and the germ theory has been accepted in its present form for only about 90 years. It is surprising to note that most of the basic concepts of chemical, physical, and biological water pollution control were known by 1900, and that from this time pollution control authorities have been involved in increasing efforts to control water pollution.

The desire to implement land treatment of waste is a case of "history repeating itself." We have passed through several major phases in which the philosophy behind wastewater treatment changed. These may be represented as follows:

> _First period_ 1840-1890. The major objective was to keep as much of the pollutants as possible out of receiving waters, particularly potential drinking waters. The efficiency and acceptability of a treatment process depended on its capability to produce a safe drinking water quality effluent. Land treatment was the most effective physical, biological, and chemical treatment process. Zero discharge was the ideal goal that was achievable in many instances.
>
> _Second period_ 1890-1972. Permissible pollution and dilution as a solution to pollution were main themes of this period. Early in this period it was proposed that treatment of the polluted waters in preparation for a safe drinking water supply was cheaper than treatment prior to discharge to receiving waters. The use and definition of the principal of natural purification principles led to a firm basis of predicting the degree of treatment which would be required to result in an acceptable discharge of pollutants.
>
> _Third period_ 1972-present. Adoption of a policy of nondegradation of natural waters, reuse of wastewaters, and minimization of the discharge of effluents. Although processes must be cost effective, by 1985 the basis of judgement of a treatment system may depend on its capability to produce drinking water quality effluents.

Much of the water pollution control activities between 1840 and 1890 were conducted without precise objectives and goals. Homes were supplied with running water and the resulting collection and discharge of the wastes created nuisances which were thought to be associated with disease in some poorly defined manner. Typhoid, cholera, and yellow fever epidemics were common and they caused great panic among the population. This provided the motivating force of that day to search for and identify solutions. In the late 1840's sewage was shown to be capable of being used in agriculture to achieve a two fold objective - that of reusing the nutrients to produce a valuable crop and production of a purified and clarified wastewater. At first this was thought to be a profitable pursuit.

Subsequently, however, the germ theory became more clearly defined, sewage treatment processes, such as the intermittent sand filter, were shown to be capable of controlling bacteria, and technology for controlling water borne diseases was rapidly instituted. By this time it was well accepted that sewage farms required careful management, they were not profitable, but under certain circumstances, the crops could pay for operaton and maintenance. However, since it was not necessary to produce a drinking water quality effluent, cheaper and more easily managed systems which could be depended upon to produce an acceptable, partially treated effluent, was sought and identified. Trickling filtration, activated sludge, and some forms of chemical treatment were instituted on a wide scale and rapidly replaced land treatment systems. During the period from 1890 to 1970, land application of wastes was merely a final disposal process.

The need to understand and define the physical, chemical, and biological cycles of land treatment did not exist, since it was primarily a disposal option. Any mention of the design basis and definition of the technology disappeared from all major texts around 1950. Thus, most practicing engineers who are 50 years old or younger, today have no formal education in land treatment technology. Only a few consulting firms retained the capability to work in this area.

As the population of the U.S. increased, the partial treatment achieved by conventional discharged technologies received increasing criticism from the general public. Eutrophication became a major issue and nutrient control became an additional objective of wastewater treatment technology. The controversy over the need to control phosphorus and the passage of legislation to prohibit phosphorus in detergents served to bring widespread public attention to the fact that sewage was being discharged only partially treated into waters from which it obtained its drinking water, into its neighbors drinking water, or what was worse, into its favorite recreational area.

The accuracy of these public concerns over nutrient pollution was of no consequence after the public attention was aroused and the political means of dealing with this important societal issue was initiated. In effect, the legislative process reflected the feeling that previous and existing attempts to solve water pollution had not achieved the goal of a clean environment and new approaches were needed. Although concern over the phosphorus issue does not illustrate the depth of the issue, it was well known that phosphorus control with land treatment was highly effective, and that soils could absorb great quantities without creating secondary problems such as large quantities of sludge. Further investigation of the possibilities of wastewater treatment with soils led to the conclusion that it was being used in several hundred instances in the U.S., and that it was a cost effective alternative to discharge systems.

THE FUTURE OF LAND TREATMENT

There are several factors which need to be changed before land treatment technology can be widely implemented. The first factor involves the development of a body of knowledge among the engineering and agricultural communities based firmly in a major research and educational program. The first prerequisite of this program would be to eliminate the concept of land disposal and replace it with the land treatment idea. The difficulty in achieving this end is that although there is a large body of information in the historical area and also much information being developed today, much of it is highly empirical. It is well accepted that processes such as trickling filters and activated sludge have certain design limitating factors and that these cannot be violated. Increasing the loading rate on an activated sludge plant in terms of pounds of organics added per volume of reactor may result in major changes in the sludge settleability and eventually in a failure of the system. Until the assimilation capacities of the soil system are known to researchers, disseminated, and understood, the designs will be subject to question and used only under highly conservative conditions.

Key areas that need accelerated dissemination of knowledge are the relationships of the movement of water, oxygen, carbon oxidation and the fate of nitrogen in soil treatment systems. It is likely that nitrogen will be a key parameter in many domestic wastewater treatment systems for many years. Effective nitrogen management will be essential to develop cost effective land treatment alternatives.

Another area of concern is to define the capability of various treatment systems to control trace organics and toxic elements. The presence of pathogens, carcinogen organics, and trace quantities of other toxic or foreign materials will increasingly provide the basis for making water pollution control treatment decisions. It is likely that the complex and efficient purifying capacity of soil treatment systems will play an important role in this area.

Finally, no major text exists in the land treatment technology area. Courses of study for environmental engineers, agricultural engineers, agronomists, planners, the general public, and others concerned with determining the quality of the environment must be available to provide the expertise needed to implement this technology. Recent development of the Cornell University educational program and the design manual will assist in making the necessary information available to the users.

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APPENDIX

APPENDIX A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OCT 3 1977

THE ADMINISTRATOR

SUBJECT: EPA Policy on Land Treatment of Municipal Wastewater

FROM: The Administrator

TO: Assistant Administrators and
Regional Administrators (Regions I-X)

President Carter's recent Environmental Message to the Congress emphasized the design and construction of cost-effective publicly owned wastewater treatment facilities that encourage water conservation as well as adequately treat wastewater. This serves to strengthen the encouragement under the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) to consider wastewater reclamation and recycling by land treatment processes.

At the time P.L. 92-500 was enacted, it was the intent of Congress to encourage to the extent possible the development of wastewater management policies that are consistent with the fundamental ecological principle that all materials should be returned to the cycles from which they were generated. Particular attention should be given to wastewater treatment processes which renovate and reuse wastewater as well as recycle the organic matter and nutrients in a beneficial manner. Therefore, the Agency will press vigorously for publicly owned treatment works to utilize land treatment processes to reclaim and recycle municipal wastewater.

RATIONALE

Land treatment systems involve the use of plants and the soil to remove previously unwanted contaminants from wastewaters. Land treatment is capable of achieving removal levels comparable to the best available advanced wastewater treatment technologies while achieving additional benefits. The recovery and beneficial reuse of wastewater and its nutrient resources through crop production, as well as wastewater treatment and reclamation, allow land treatment systems to accomplish far more than most conventional treatment and discharge alternatives.

The application of wastewater on land is a practice that has been used for many decades; however, recycling and reclaiming wastewater that may involve the planned recovery of nutrient resources as part of a designed wastewater treatment facility is a relatively new technique. One of the first such projects was the large scale Muskegon, Michigan, land treatment demonstration project funded under the Federal Water Pollution Control Act Amendments of 1966 (P.L. 84-660), which began operations in May 1974.

Reliable wastewater treatment processes that utilize land treatment concepts to recycle resources through agriculture, silviculture and aquaculture practices are available. The technology for planning, designing, constructing and operating land treatment facilities is adequate to meet both 1983 and 1985 requirements and goals of P.L. 92-500.

Land treatment is also presently in extensive use for treatment of many industrial wastewaters, particularly those with easily degraded organics such as food processing. Adoption of suitable in-plant pretreatment for the removal of excessive metals and toxic substances would expand the potential for land treatment of industrial wastewater and further enhance the potential for utilization of municipal wastewater and sludges for agricultural purposes.

APPROACH

Because land treatment processes contribute to the reclamation and recycling requirements of P.L. 92-500, they should be preferentially considered as an alternative wastewater management technology. Such consideration is particularly critical for smaller communities. While it is recognized that acceptance is not universal, the utilization of land treatment systems has the potential for saving billions of dollars. This will benefit not only the nationwide water pollution control program, but will also provide an additional mechanism for the recovery and recycling of wastewater as a resource.

EPA currently requires each applicant for construction grant funds to make a conscientious analysis of wastewater management alternatives with the burden upon the applicant to examine all available alternative technologies. Therefore, if a method that encourages water conservation, wastewater reclamation and reuse is not recommended, the applicant should be required to provide complete justification for the rejection of land treatment.

Imposition of stringent wastewater treatment requirements prior to land application has quite often nullified the cost-effectiveness of land treatment processes in the past. We must ensure that appropriate Federal, State and local requirements and regulations are imposed at the proper point in the treatment system and are not used in a manner that may arbitrarily block land treatment projects. Whenever States insist upon placing unnecessarily stringent preapplication treatment requirements upon land treatment, such as requiring EPA secondary effluent quality in all cases prior to application on the land, the unnecessary wastewater treatment facilities will not be funded by EPA. This should encourage the States to re-examine and revise their criteria, and so reduce the cost burden, especially to small communities, for construction and operation of unnecessary or too costly facilities. The reduction of potentially toxic metals and organics in industrial discharges to municipal systems often is critical to the success of land treatment. The development and enforcement at the local level of pretreatment standards that are consistent with national pretreatment standards should be required as an integral part of any consideration or final selection of land treatment alternatives. In addition, land treatment alternatives must be fully coordinated with on-going areawide planning under section 208 of the Act. Section 208 agencies should be involved in the review and development of land treatment options.

Research will be continued to further improve criteria for preapplication treatment and other aspects of land treatment processes. This will add to our knowledge and reduce uncertainties about health and environmental factors. I am confident, however, that land treatment of municipal wastewaters can be accomplished without adverse effects on human health if proper consideration is given to design and management of the system.

INTER-OFFICE COORDINATION

The implementation of more recent mandates from the Safe Drinking Water Act (P.L. 93-532), the Toxic Substances Control Act (P.L. 94-469), and the Resource Conservation and Recovery Act of 1976 (P.L. 94-580) must be closely coordinated with the earlier mandate to recycle wastes and fully evaluate land treatment in P.L. 92-500. Agencywide coordination is especially important to the proper management of section 201 of P.L. 92-500, because the construction and operation of thousands of POTW's involve such a broad spectrum of environmental issues. A concerted effort must be made to avoid unilateral actions, or even the appearance of unilateral actions, which satisfy a particular mandate of one Act while inadvertently conflicting with a major Agency policy based upon another Act. The intention of P.L. 92-500, as it concerns land treatment, is compatible with the pertinent aspects of more recent environmental legislation.

ACTION REQUIRED

Each of you must exert maximum effort to ensure that the actions of your staffs reflect clearly visible encouragement of wastewater reclamation and recycling of pollutants through land treatment processes in order to move toward the national goals of conserving water and eliminating the discharge of pollutants in navigable waters by 1985.

This policy will apply to all future municipal construction grant activities, as well as all current grant applications in the Step 1 category that have not been approved as of this date. Detailed information and guidance for implementation of this policy is under preparation and will be issued in the near future.

APPENDIX B. EARLY SEWAGE FARMS IN BRITAIN AND THE ECONOMICS OF THE FACILITIES (From Birch, 1879).

Sewage Farm	Year Started	Population Served	Size of Field (Acres)	Comments
Aberdeen	1877	-	50	Farmers paid 5 pounds* per year per acre land preparation extensive, cost 30 to 40 pounds per acre. Thus, system lost money.
Aldershot	1865	8,000	100	Free lease of land to farmers to improve it. Land was of very poor value, after operation it was leased at 20 pounds per acre to dairy farmers.
Altrincham	1872	12,000	55	Operated by municipality. Expenses fell short of income by 130 pounds per year. Sedimentation pretreatment.
Bodmin	1876	4,000	17	No pretreatment. Cottages within 50 yards - no complaints.
Carlisle	1860	21,000	30	Farmer leased farm for 4 pounds per acre per year and rented it for grazing at 8 pounds/ac/yr.
Chelmsford	1869	8,000	70	Pretreatment with screening. This was reported to be a profitable operation.
Cheltenham	1869	50,000	131	Land cost 80 pounds/ac. "Roots grown on the private dairy farmers land under sewage, won first prize at an annual show at Cheltenham, till they were excluded from the competition with the produce from ordinary farms; they were shown with equal success, and the same result at Glowcester.
Ghorley	-	-	-	Reported to pay for itself.
Cleator Moor	1876	8,000	40	Irrigation and grazing carried on simultaneously.

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*In the 1960's, one English pound sterling was valued at about $2.50 (U.S.).

APPENDIX B (Concluded) EARLY SEWAGE FARMS IN BRITAIN AND THE ECONOMICS OF THE FACILITIES (From Birch, 1879).

Sewage Farm	Year Started	Population Served	Size of Field (Acres)	Comments
Cockermouth	1877	5,115	16	-
Credition	-	4,000	-	-
Denbigh	-	5,823	250	Farmers pay 110 pounds/year for the sewage.
Devizes	1869	7,000	-	-
Doncaster	1874	20,000	263	-
Edinburgh	1769	2.5×10^6 gpd	323	Grass is bought and harvested by local dairymen - Hay yield 40 ton/ac, rye grass produces up to 60 tons/ac.
Guisborough	1871	6,000	21	Operated in private lands at a profit.
Handswork	1861	1,000	-	-
Hoddesdon	1878	2,000	17	-
Leamington	-	22,000	-	Sewage pumped 2 miles and had an elevation increase of 130 feet.
Ormskirk	1875	6,000	40	-
Penrith	1869	7,000	70	-
Rugby	-	9,000	190	Contributed more to sewage utilization facts than any other place but Edinburgh.
Ruthin	-	3,000	112	-
South Molton	-	3,000	-	-

APPENDIX C. PLACES THAT HAVE (OR ARE STILL USING) LAND TREATMENT (Hartman, 1975; Rideal, 1906; Rafter and Baker, 1894; Hutchins, 1939).

Modern Surveys of Land Treatment are not Included Here, Such as Sullivan, et al. (1973).

Place	Year Started	Year Changed to Treatment and Discharge	Area Used (Ac)	Amount of Flow (MGD)/ Population
Australia				
Melbourne	1898	Plan underway	26,880	96
Canada				
Victoria	1901	-	-	-
Egypt				
Cairo	1915	-	3,000	
Britain				
Aberdeen	1877	-	-	-
Aldershot	1865	-	-	-/8,000
Altrincham	1872	-	55	-/12,000
Banburg	-	-	-	-/12,700
Barston	-	-	-	-
Bedford	1868	-	155	1.2/-
Birmingham	1867	1903	500	15.6/-
Bedmin	1876	-	17	-/3,000
Braintree	1860	-	30	-/5,000
Burton	-	-	430	-/46,400
Cambridge	-	-	-	-
Carlisle	1860	-	60	-/21,000
Chelmsford	1869	-	70	-/8,000
Cheltenham	1869	-	131	-/50,000
Chesterfield Farm	-	-	-	-
Chorley	-	-	-	-
Cleator Moor	1876	-	40	-/800
Cockermouth	1877	-	16	-/5,115
Coventry	-	-	-	-
Credition	-	-	-	-/4,000
Croydon	1860	1969	630	5.6/35,000
Parlington	1876	1936	-	-
Desborough	-	-	-	-
Doncaster	1873	-	263	-/23,600
Edinburgh	1650	1900	250	2.5/-
Eucles	-	-	-	-
Glastonbury	-	-	250	-
Guisbourough	1871	-	21	-/6,000

APPENDIX C. (CONTINUED). PLACES THAT HAVE (OR ARE STILL USING) LAND TREATMENT (Hartman, 1975; Rideal, 1906; Rafter and Baker, 1894; Hutchins, 1939).

Place	Year Started	Year Changed to Treatment and Discharge	Area Used (Ac)	Amount of Flow (MGD)/ Population
Handsworth	1861	-	21	-/1,000
Hoddesdon	1878	-	17	-/2,000
Leamington	1870	1929	-	-/22,000
Leicester	-	1952	1,710	9.6/-
Manchester	-	1904	-	-
Nottingham	1880	1930	651	-/259,000
Ormskirk	1875	-	40	-/6,000
Otley	-	-	-	-
Oxford	1880	-	318	1.5/5,000
Penrith	1869	-	70	-/7,000
Plympton	-	-	100	-/3,000
Perth	-	-	-	-
Reading	1874	1904	869	3.3/65,000
Riding	-	-	-	-
Ripon	-	-	-	-
Rugby	1853	-	190	-/9,000
Stretford	1877	1903	77	0.8/-
South Molton	-	-	-	-/3,000
Turnbridge Wells	-	-	310	-/30,000
Tyldeslay	-	1903	-	-
Warwick	1867	-	130	1.2/12,000
Wigam	-	-	420	-/59,000
Weherhampton	-	-	-	-
West Houghton	-	1900	-	-
Wilmslaw	-	-	-	-
Wimbledon	1877	-	61	0.67/25,000
Withington	-	-	-	-
Wrexham	1871	-	80	0.4/12,000
France				
Paris	1869	-	16,000	79.2/-
Rheims	-	-	-	-
Germany				
Berlin	1874	-	68,000	40/-
Bielefeld	-	-	-	-
Braunschweig	1896	-	10,865	16/-
Bremen	1915	-	-	-
Breslau	1881	-	741	9.3/-
Bunzlau	1630	-	-	-
Celle	1870	-	-	-

APPENDIX C. (CONTINUED). PLACES THAT HAVE (OR ARE STILL USING) LAND TREATMENT (Hartman, 1975; Rideal, 1906; Rafter and Baker, 1894; Hutchins, 1939).

Place	Year Started	Year Changed to Treatment and Discharge	Area Used (Ac)	Amount of Flow (MGD)/ Population
Danzig	1871	-	385	3.6/-
Darmstadt	1885	-	-	-
Dortmund	1899	-	-	-
Freiburg	1890	-	-	-
Konigsberg	1899	-	-	-
Leipzig	-	-	-	-
Liegnitz	1894	-	-	-
Munster	1903	-	-	-
Stadtilm	1909	-	-	-
Ulzen	1900	-	-	-
India				
Bombay	1877	-	-	-
Delhi	1913	-	-	-
New Delhi	1913	1938	1,250	-
Italy				
Florance	-	-	-	-
Milano	-	-	-	-
Mexico				
Mexico City	1900	-	111,746	1570/-
Poland				
Bielefield	-	-	1,531	-
Lodz	-	-	-	-
Lower Silesia	1906	-	-	-
Ostrow Wielkopolski	1911	-	105	-
Russia				
Moscow	1900	1963	6,500	-
South Africa				
Johannesburg	1912	1935	-	-
United States				
Abiliene, TX	1949	-	-	-
Bakersfield, CA	-	-	2,500	10/-
Boulder, CO	1890	-	-	-
Colorado Springs, CO	1889	-	-	-/11,140

APPENDIX C. (CONCLUDED) PLACES THAT HAVE (OR ARE STILL USING) LAND TREATMENT (Hartman, 1975; Rideal, 1906; Rafter and Baker, 1894; Hutchins, 1939).

Place	Year Started	Year Changed to Treatment and Discharge	Area Used (Ac)	Amount of Flow (MGD)/ Population
Burlington, NJ	1892	-	-	-
Cheyenne, WY	1883	-	-	-/11,690
Delano, CA	-	-	-	-
Deming, NM	1913	-	-	-
Fresno, CA	1890	-	2,000	14(in 1974)/10,816(1890)
Hanford, CA	-	-	160	1.5/-
Haworth, NJ	1907	-	-	-
Helena, MT	1889	-	-	-/13,834
Highstown, NJ	1913	-	-	-
Kingsville, TX	-	1959	-	-
Las Vegas, NV	-	-	-	-
Los Angeles, CA	1883	1907	-	-/50,395
Lubbock, TX	1915	-	-	-
Midland, TX	-	-	500	4.5/-
Mt. Vernon, CA	-	-	-	-
Oildale, CA	1947	1973	400	2.4/-
Palm Springs, CA	-	-	100	1/-
Pasadena, CA	1893	-	300	-/4,882
Pleasantown, CA	1911	-	181	1.3/-
Pullman, IL	1881	-	140	-
Redding, CA	1888	-	-	-/1,821
Salt Lake City, UT	1890	-	-	-
Santa Rosa, CA	1889	-	-	-/5,220
Stockton, CA	1892	-	-	-/14,424
San Angelo, TX	-	-	700	5/-
Trinidad, CO	1892	-	-	-/5,523
San Antonio, TX	1900	-	1,500	-
San Bernadino, CA	-	-	-	-
Santa Rose, CA	-	-	-	-
Smithville, NJ	-	-	-	-
South Framingham, MA	1889	-	-	-
Torrance, CA	1913	-	-	-
Tucson, AR	1915	1965	-	-

APPENDIX D

LIST OF WESTERN CITIES USING IRRIGATION OF SEWAGE IN 1934 AND 1937 (Hutchins, 1939)

IRRIGATION WITH SEWAGE TAKEN DIRECTLY FROM OUTFALLS OR DISPOSAL PLANTS

Arizona: Casa Grande, Nogales, Phoenix,* Tucson.
California: Bakersfield, Banning, Chino, Cloverdale, Colfax, Colton, Corcoran, Dixon, Elsinore, Exeter, Fowler, Fresno, Hanford, Hemet, Indio, Kingsburg, Lemoore, Livermore, Lodi,** Madera, Manteca, Marysville, Merced, Modesto, Ontario, Orland, Pasadena, Pomona, Ripon, Riverside, San Luis Obispo, Santa Maria, Santa Paula, Santa Rosa, Selma, Sonoma, St. Helena, Susanville, Tulare, Turlock, Ukiah, Vacaville, Visalia, Wasco,† Whittier, Woodland, Yreka.
Colorado: Greeley.
Idaho: Glenns Ferry, Meridian.
Kansas: Liberal, Scott City.
Montana: Anaconda, Helena, White Sulphur Springs.
New Mexico: Clovis, Portales, Sante Fe.
Oregon: Ashland, Burns.
Texas: Abilene, Amarillo, Baird, Breckenridge, Brownfield, Canyon, Carlsbad (State Sanitarium), Childress, Coleman, Dublin, Falfurrias,†† Georgetown, Karnes City, Kerrville, Kingsville, Lubbock, Midland, Mission, Munday, Plainview, Robstown, Roscoe, Rotan, San Angelo, San Antonio, San Marcos (irrigation with sludge), Snyder, Stamford, Stephenville, Sweetwater, Tahoka, Uvalde.
Utah: Brigham, Richfield, Salt Lake City, St. George.
Washington: Pomeroy, Walla Walla.
Wyoming: Cheyenne.

IRRIGATION WITH SEWAGE DIVERTED FROM PUBLIC STREAM CHANNELS

Arizona: Phoenix.
California: Brea, Pasadena, San Bernadino, Santa Rosa, Tracy.
Colorado: Denver, Greeley.
Nebraska: Hastings.
Neveda: Reno.
New Mexico: Raton.
Oregon: Ashland, Medford.
South Dakota: Rapid City.
Texas: San Angelo.
Utah: Ogden.
Washington: Walla Walla.
Wyoming: Cheyenne.

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* *Direct Irrigation only on park surrounding plant; not considered in total figures.*

** *Effluent taken directly into irrigation district canal.*

† *Creamery waste only.*

†† *Sewage irrigation previously practiced and abandoned, just now being resumed.*

APPENDIX E

THIS IS A SUMMARY OF THE REVIEW OF LAND TREATMENT TECHNOLOGY CONDUCTED IN THE LATE 1800's AND IS A DIRECT QUOTE FROM RAFTER (1887, 1889).

The more important of the general principles discussed in this paper are brought together at this point for convenience of reference:

(1) Sewage purification is an imperative duty which municipalities owe to the owners of riparian rights, and which can not be neglected by municipalities without such an infringement upon those rights as it is now well established may be prevented by legal process.

(2) Sewage utilization should go hand in hand with purification. When operated with reference to all the necessary conditions, a proper degree of purification may be attached as well as satisfactory utilization.

(3) The proper method of utilizing sewage is, for purposes of irrigation, by means which do not differ, except in matters of detail, from those of ordinary irrigation as practiced abroad for centuries.

(4) In order to utilize sewage to the best advantage, the towns should construct, at thier own expense, intermittent filtration areas on which the sewage may be efficiently purified when not required for use in agriculture. Farmers utilizing sewage in agriculture should be required to take it only as needed for the best results on crops.

(5) The theory of the action of intermittent filtration is in effect the theory of purification as effected by broad irrigation, the difference between the two being chiefly a matter of detail.

(6) In the purification of a strong acid sewage from manufacturing towns it may sometimes become desirable to treat the sewage by a chemical process before utilizing it in agriculture. For this purpose lime is the chemical commonly used.

(7) In case the effluent from sewage purification works or areas is to be passed into streams which are the source of drinking water for towns farther down, the degree of purification should necessarily be high. The experiments of the Massachusetts State Board of Health show that there is no trouble in removing from 95 to 99 1/2 per cent of the organic impurity, as indicated either by the chemical constituents or by the bacteria. When as much as 99 per cent is removed, the sewage becomes chemically purer than the water of many wells, and there is, so far as known, absolutely no reason why it may not pass safely into a stream used as the source of a public water supply.

(8) Intermittent filtration areas are best constructed of coarse mortar sand, as shown by the experiments of the Massachusetts State Board of Health.

(9) Intermittent filtration is chiefly a biological process, in which the nitrifying organisms, with the assistance of oxygen and the minerals naturally in solution in sewage, resolve objectionable organic matter into mineral nitrates, etc., the whole process, when properly conducted, taking place without the production of objectionable odor. The conditions for successful treatment are, generally, intermittency of application and open spaces in the filtering material to which common air may easily gain access.

Such filters may be expected to purify from 30,000 to 100,000 gallons per acre per day, the amount depending upon the quality of the material in respect to sand and water content, as defined by the studies of Mr. Allen Hazen.[1]

(10) Sewage may be purified by broad irrigation at all seasons of the year at any place where the mean air temperature of the coldest month is not lower than about 20° to 25°F., while by the use of intermittent filtration it may be purified fairly well down to a limit of 18° to 20°F., provided the sewage reaches the purification area at a temperature not lower than about 45°F.

(11) From the experience gained abroad it is clear that we may successfully cultivate almost any of the ordinary agricultural productions of the United States on sewage farms, due regard being had in every case to the special conditions required for each particular crop.

(12) The most efficient purification of sewage can be attained by its application to land.

(13) On properly managed sewage farms the utilization of sewage is not prejudicial to health.

(14) In comparing the results of sewage utilization as thus far obtained in the United States with the results obtained abroad it is clear that, generally speaking, we have not been specially successful. As one chief step toward a remedy for this we need to create in this country a class of sewage-farm managers who are thoroughly familiar with all phases of the question. Thus far the management of American sewage farms has been usually in the hands of committees of municipal councils having little or no knowledge of the real governing conditions.

(15) The experience in England, Germany, and France, and also that gained in this country, all points to intermittent filtration relief areas, on which any surplus sewage not required in agriculture may be purified, as the rational method of procedure.

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[1] *From 30,000 to 100,000 gallons of ordinary raw town sewage may be so thoroughly purified that it may be admitted to streams from which public water supplies are taken. If a less thorough purification is required, or if the sewage has been previously treated with lime, from 200,000 to 300,000 gallons per acre per acre per day may be successfully purified.*

APPENDIX F

ANNOTATED BIBLIOGRAPHY OF SUPPLEMENTAL REFERENCES FROM RAFTER (1899)

Austin (Henry). Report on the means of deodorizing and utilizing the sewage of towns. Paper; 8vo. London, 1857.

Discusses a large number of the more important questions in sewage utilization in such a way as to be of great value to the student of the present day.

Backhouse (Benjamin). An account of Liernur's sewerage system in its present state of development based upon personal inquiry. By the chairman of the city of Sydney Improvement Board. Pamphlet; 8vo. London, 1887.

Baumeister (R.). The cleaning and sewerage of cities - sewerage, sewage disposal, street cleaning. Translation; 8vo. New York, 1891.

A concise statement of the German views on sewerage, sewage disposal, and street cleaning. Contains illustrations and is especially valuable for the reader who wishes to survey the whole field of the German view without reading a large number of works. As remarked in the introduction, prepared by Rudolph Hering, the American reader should remember that this work was prepared primarily for German engineers and for the conditions prevalent in the German Empire.

Birmingham sewage inquiry. 8vo. Birmingham and London, 1871.

This report contains a very thorough review of sewage purification as it existed in 1871, together with description and cuts of the pail system as used in Liverpool, Manchester, Rochdale, Birmingham, etc. The reader should remember, however, in reading the old reports, that many of the appliances which are illustrated have been improved without recent dates, and that the statements illustrations can only be safely taken after one has obtained full knowledge of the subject and consequent power of selection.

Burn (R. Scott). Outlines of modern farming. 6th edition. 12 mo. London, 1888.

Treats extensively among other subjects of the utilization of town sewage, irrigation, etc.

Corfield (W.H.) The treatment and utilization of sewage. 3rd edition, revised and enlarged by the author and Louis C. Parks. 8vo. London, 1887.

In this work the question of sewage utilization is examined at considerable length, and many useful conclusions are reached.

Crimp (W. Santo). Sewage disposal works. A guide to the construction of works for the prevention of pollution by sewage of rivers and estuaries. 1st edition. 8vo. London, 1890. 2d edition. London, 1894.

Contains descriptions up to date of a large number of the more important English sewage disposal works.

Dempsey (G.D.). Drainage of lands, towns, and buildings. Revised edition with large additions of recent practices in drainage engineering, by D. Kinnear Clark. 12mo. London, 1890.

Dibdin (W.J.). Report of experiments on the filtration of sewage effluent (from the London main drainage works) during the years 1892-1895, inclusive. Paper; 4to. London, 1895.

Frankland (Percy and Mrs. Percy). Micro organisms in water, their significance, identification, and removal. 8vo. London, 1894.

Contains a statement of the relation of sewage-polluted water to disease.

Gray (Samuel M.). Proposed plan of a sewerage system for the disposal of the sewage of the city of Providence. Made by order of the city council of the city of Providence. Paper; 8vo. Providence, 1884.

Contains an account of a large number of sewage purification plants abroad as visited by Mr. Gray, together with recommendations for the partial purification of sewage of Providence by chemical treatment, followed by its discharge into tide water at a point where it could not become a nuisance along the adjacent beaches.

Health of Towns Commission. This commission made two reports - the first, 1844, published in two 8vo. vols.: the second, in 1845, also in two 8vo. vols.

These two reports may be taken as the beginning of sanitary science in England and in the civilized world generally. These reports should be studied by any person wishing to study the whole subject of sewage utilization, by way of showing the magnitude of the evil which has been combatted and greatly mitigrated since 1844.

Hill (John W.). Water supplies for eitht cities in relation to typhoid-fever rates. An address before the Society of Municipal Improvements, Chicago, October 9, 1896. Paper; 12mo. 8 pp. Cincinnati, 1896.

Institution of Civil Engineers, Proceedings of Vols. I-CXX. 8vo. London, 1838-1895.

Contain a large amount of information on river pollution and sewage deodorization, filtration, interception, irrigation, manure, precipitation, and sewage utilization generally. Detailed subject indexes have been issued from Vols. I-LVIII and from Vols. LIX-CXVIII, to which reference may be made for nearly every phase of the subject as discussed in England for the last forty to fifty years.

Jones (Charles). Refuse destructors. 2d edition. 8vo. London, 1894.

Contains detailed information as to the result of garbage destruction by fire, as well as a paper on the utilization of town refuse for power production, by Thomas Tomlinson.

Kiersted (Wyncoop). A discussion of the prevailing theories and practice relating to sewage disposal. 12mo. New York, 1894.

The author believes that the rivers of the country are, on the whole, the natural place for disposing of sewage. In his view the natural forces of nitrification will purify the sewage in streams somewhat the same as on land.

Kinzett (C.T.). Nature's hygiene. A systematic manual of natural hygiene. 4th edition. 8vo. London, 1894.

Local Government Board. Reports of the medical officer.

The reports of the medical officer of the privy council and local government board have contained for many years much information of interest and value relating to sewage purification and utilization. The student of the subject will find in these reports a vast amount of important matter. In the supplement to the report of the medical officer for 1891 may be found a study of enteric fever in the valley of the river Lee. In the supplement to the report for 1887 may be found papers giving full statistics of diarrhea and diphtheria in England. The first of these is a report by Dr. Ballard of the cause of the mortality from diarrhea which is observed principally in the summer seasons of the year in English communities, and the second is a statistical study by Dr. Longstaff on the geographical distribution of diphtheria in England and Wales. Dr. Ballard's statistical inquiry included the years from 1880 to 1888. while Dr. Longstaff's included the twenty-six years ending with 1880. The relation of these two diseases to sanitary conditions is set forth in many tables and diagrams with great clearness.

Lowcook (Richard Sidney). Experiments on the filtration of sewage. Excerpt from Proceedings Institution Civil Engineers, Vol. CXV. Paper; 8vo. London, 1893.

Mason (William P.). Water supply, chemical and sanitary. 8vo. New York, 1896.

Contains an excellent statement of drinking water as affected by sewage pollution in its relations to disease.

Massachusetts Drainage Commission, Report of. 8vo. Boston, 1886.

This commission was authorized by the Massachusetts legislature to consider and report systems of drainage for the Mystic, Blackstone, and Charles river valleys. In 1885 a report of great value was submitted, in which questions of stream pollution and sewage disposal are discussed at length. The engineer of the commission, Elliot C. Clark, also submitted a report in which he gave the details of the problem of prevention of stream pollution and methods of sewage purification as applied to the river valleys named. One of the best of the early American reports.

APPENDIX F (Continued)

Metropolitan sewage discharge. Report of Royal Dommissioners. 4 vols. of reports; minutes of evidence; appendixes, etc. 4to. London, 1884, 1885.

> *Presents every phase of question of disposal of sewage of London as it existed twelve years ago.*

Metropolitan water supply, Report of Royal Commission on. 6 vols. General report; minutes of evidence; appendixes; index; plans, etc. 4to. London, 1893.

> *The most recent and extensive information as to pollution of streams and its effect on the water supply of the metropolis as applied to the rivers Thames and Lee, from which that supply is drawn.*

Munroe (John M.H.). Composition and manurial value of filtered pressed sewage sludge. Reprint from the Journal of the Society of Chemical Industry, January 29, 1885. Manchester, 1885.

Philadelphia Water Department, Annual Reports of the Chief Engineer, 1883 to 1886, inclusive.

> *These reports contain the results of an investigation as to the pollution of the water supply of the city of Philadelphia by sewage, together with the reports on additional supplies from unpolluted or nearly unpolluted or nearly unpolluted sources, with methods of preventing pollution, etc. They may be referred to for much valuable information on the general question of pollution of streams and its attendant evils.*

Rivers Pollution Commission (first commission). Report of the commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers. 10 vols. 4to. London, 1870, 1871, 1872, 1874.

> *This commission made six reports in all. The first report, in two volumes, treats of the pollution of the basin of the rivers Mersey and Ribble and of the best means of preventing pollution therein. The second report is taken up with a description of the A, B, C process of treating sewage. The third report, in two volumes, discusses the pollution arising from the woolen manufacture and processes connected therewith. The fourth report treats of the pollution of the rivers of Scotland, and gives special consideration, among other subjects, to the pollution arising from paper-mill wastes, etc. The fifth report, in two volumes, treats of the pollution arising from mining operations and metal manufactures. The sixth report, in one volume, treats of the general subject of domestic water supply of Great Britain. In this report Dr. Edwin Franklin, the chemist member of the commission, has here worked out in detail the method of water analysis which he designated as the combustion method. A large amount of information about water supplies from cultivated and uncultivated areas and the contamination of water from manured and unmanured, cropped and uncropped land is given, the whole forming a vast body of sanitary information pertinent to present conditions.*

APPENDIX F (Concluded)

Royal Sanitary Commission, Report of. Second report. 4to. London, 1871.

Contains a history of the English sanitary laws up to that date, with suggestions for new statute, etc.

Sewage disposal. Report of a committee appointed by the president of the local government board to inquire into the several modes of treating town sewage. Paper; 8vo. London, 1876.

Contains many details of sewerage work carried out in England to that date, with a large number of analyses of raw and effluent sewage at several sewage farms. In appendix No. 7 is given a list of a large number of patented processes for treating sewage and producing artificial manure therefrom, as taken out from between the years 1856 and 1875 inclusive. The report is also accompanied by a folio of plans, giving details of a number of the more interesting sewage-disposal works of that date.

Sewage of Towns, Report from the select committee on. Two reports, in 2 volumes. First report ordered to be printed April 10, 1862, and the second report April 29, 1862. 4to. London, 1882.

Sewage of Towns Commission. Three reports. 8vo. London, 1858, 1861, 1865.

These reports contain the detail of elaborate investigations made by a royal commission appointed to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses. Elaborate cultivation and feeding experiments were pursued, extending over a period of several years, the results of which were presented in great detail in the second and third reports. In the appendix to the first report may be found an account of a visit made by a committee of the commission to Milan, Italy, for the purpose of examining the sewage utilization works which had been carried out at that place. This committee reported under date of December, 1857, that the experience of the irrigation around Milan adds a striking proof to those already obtained as to obtained as to the value in agriculture of a command of pure water and of the immense increase of that value obtained by the addition of sewage combined with the higher temperature derived by the liquid in its passage through the town.

Waring (George E., Jr.). Purification of sewage by forced aeration. Report of an experimental investigation of the value of the process of purifying sewage by means of artifically aerated bacterial filters. Paper; 8vo. Newport, Rhode Island, 1895.

APPENDIX G

RECOMMENDATIONS WHICH WOULD ENCOURAGE MORE RAPID AND EFFECTIVE ADOPTION OF RELIABLE RECYCLING AND RECLAMATION WASTEWATER TREATMENT ALTERNATIVES

(Seabrook, 1977)

1. Provide increased internal E.P.A. agency-wide program office coordination for implementation of the Water Quality Act Amendments (P.L.92-500), the Safe Drinking Water Act (P.L.93-523), the Toxic Substances Control Act (P.L.94-469), and the Resource Conservation and Recovery Act of 1976 (P.L.94-580).

2. Include conservation of energy and material resources in cost-effective planning to obtain lowest cost operations, maintenance, and capital investment facilities.

3. Development of more uniform National guidelines on preapplication treatment, buffer zones, and groundwater protection.

4. Increase the use of U.S. E.P.A. construction grant funds for land application demonstration projects.

5. Develop an effective and rapid means of transferring land treatment information to the consultants and other decision makers operating in the waste treatment fields.

6. The Farmers Home Administration (F.H.A.) and the Environmental Protection Agency should develop more effective coordination when dealing with rural communities. Since F.H.A. has authority to make grants and/or loans to communities under 10,000 in population for water and sewage treatment facilities, all "Step I Grants" should be reviewed by F.H.A. before the grant is finalized by the E.P.A. regional offices. One method of achieving this type of coordination would be to develop a special task force in each E.P.A. regional office which would include an F.H.A. engineer in order to provide assistance in evaluating alternative waste treatment systems for small communities.

7. Flexible but proven national guidelines for the development of land treatment systems need to be developed. The 1975 California regulations would be good examples to start with.

8. Redefine the reference technology for best practicable treatment to refer to well designed and well operated treatment systems.

9. Where appropriate, cost comparison and decisions should be made between discharge technologies which produce water quality equivalent to land treatment systems.